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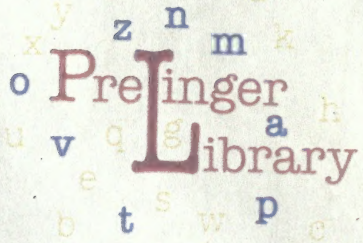

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TECHNICAL BULLETIN No. 300 MAY, 1932

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

SUSCEPTIBILITY AND RESISTANCE OF BERBERIS AND RELATED GENERA TO PUCCINIA GRAMINIS[1]

By MOSES N. LEVINE, *Pathologist, Division of Cereal Crops and Diseases*, and RALPH U. COTTER, *Associate Pathologist, Division of Barberry Eradication, Bureau of Plant Industry*[2]

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INTRODUCTION

Now that it has been shown conclusively that new parasitic races and physiologic forms of stem rust, *Puccinia graminis* Pers., may originate through hybridization on barberries, where the sexual stage of the stem-rust fungus develops, the question of exactly what intermediate hosts can and do harbor this destructive parasite assumes more than usual significance. Information regarding the susceptibility of Berberidaceae to stem rust is rather meager in the literature of uredinology. Consequently, many exsiccati specimens in various herbaria in the United States and abroad were examined for rust infection; and numerous species, varieties, and hybrids of Berberis and related genera were artificially inoculated with sporidia of different races of *P. graminis*. In addition, field observations on the susceptibility of barberries under natural conditions have been made for a number of years by various persons connected with cereal-rust epidemiology studies. Most of these observations were made at the

[1] Cooperative investigations between the Bureau of Plant Industry, U. S. Department of Agriculture, and the State Agricultural Experiment Station of the University of Minnesota.

[2] The writers are indebted to E. C. Stakman, professor of plant pathology, University of Minnesota, and agent, Division of Barberry Eradication, Bureau of Plant Industry, U. S. Department of Agriculture, for initiating the present studies and for numerous and extended field observations and herbarium examinations; to H. B. Humphrey, principal pathologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Noel F. Thompson, plant pathologist, Wisconsin State Department of Agriculture, and R. S. Kirby, professor of plant pathology, Pennsylvania Agricultural Experiment Station, for valuable observations on the rust infection of barberries at Highland Park, Rochester, N. Y.; to S. H. Essary, botanist, Tennessee Agricultural Experiment Station, for the generous supply of plants of Caulophyllum, Diphylleia, Jeffersonia, and Podophyllum; to B. Y. Morrison, senior horticulturist, Division of Foreign Plant Introduction, Bureau of Plant Industry, for furnishing many species and varieties of Berberis and related genera; to the Bureau of Parks, Rochester, N. Y., for the liberal supply of seed of various barberry species, varieties, and hybrids; to E. B. Lambert, associate pathologist, Division of Mycology and Disease Survey, and to L. W. Melander, associate pathologist, Division of Barberry Eradication, for their help in determining the reaction of a number of species of Berberis previously not known to be susceptible to stem rust, and for furnishing numerous plants of the common barberry used as controls in the inoculation experiments; and to S. F. Blake, senior botanist, Division of Botany, and B. Y. Morrison, Division of Foreign Plant Introduction, Bureau of Plant Industry, for helpful advice regarding the synonymy of the plants under consideration.

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Arnold Arboretum of Harvard University; at Highland Park, Rochester, N. Y.; and in N. E. Hansen's barberry garden at Brookings, S. Dak. Lists of susceptible and resistant barberries, compiled as a result of these studies, have been published from time to time by the Division of Cereal Crops and Diseases.[3] This bulletin supersedes all former reports and contains all the results of artificial inoculations made in the greenhouse at University Farm, St. Paul, Minn., up to the present time, the direct observations made in the field and herbaria, and the reports of other investigators that appeared in literature.

MATERIAL AND METHODS

The larger part of the telial material used in the inoculation experiments came from collections made in early spring in fields and meadows of the spring-wheat area, particularly in Minnesota and Montana. When the rusted grains and grasses were gathered in the fall the straw was tied up in small bundles and fastened to a wire stretched between two trees, where it was kept during the winter under approximately natural conditions.

Inoculations were made on plants having young and tender leaflets. (Fig. 1.) About a dozen rusted straws were spread on a wire screen suspended above the plants in an incubation chamber covered with a close-fitting glass top. The germination of the teliospores was facilitated by sprinkling the rusted straw twice daily with tap water. The youngest and most tender parts of the barberries were thus subjected to a continuous shower of sporidia. After 72 hours the inoculated plants were removed from the moist chambers, put in a shady place for two or three days to prevent killing of the leaves by the sun, and then moved to different compartments on the greenhouse bench.

Pycnia appeared in 5 to 7 days after date of inoculation, and aecia usually developed about 5 to 7 days later, depending on the prevailing environmental conditions. Infection resulted, at one time or another, from teliospores of all but one of the stem-rust races found in North America. The exception was *Puccinia graminis phleipratensis* (Eriks. and Henn.) Stak. and Piem., which has not infected any member of the barberry family thus far tested.

NOMENCLATURE OF BERBERIS AND RELATED GENERA

The barberry family includes a great many species, varieties, and hybrids. This is particularly true of the genus Berberis. Not a few of the specific and varietal names in use are synonymous. These synonyms sometimes are puzzling and conflicting and, therefore, the barberry nomenclature has been a vexing problem to the plant pathologist and especially to the rust student. In Table 1 only members of the Berberidaceae are given for which there is some definite information, obtained either from literature or from original experiments and direct observations, regarding the relative susceptibility or resistance to stem rust.

Most of the information regarding nomenclature was obtained from the works of Schneider (*14*, *15*, *16*, *17*) [4] and Rehder (*10*, *11*),

[3] The first of these lists appeared in the following article: STAKMAN, E. C., and LEVINE, M. N. A PARTIAL REPORT ON THE SUSCEPTIBILITY AND RESISTANCE OF BERBERIS AND RELATED GENERA TO STEM RUST. U. S. Dept. Agr., Bur. Plant Indus., Cereal Courier 15: 278–287. 1923. [Mimeographed.] Subsequent reports appeared in later issues of the same periodical.

[4] Italic numbers in parentheses refer to Literature Cited, p. 26.

and from the lists published in the Index Kewensis (*4*, *9*). Schneider was considered the final arbiter in all doubtful cases pertaining to the synonymy of Berberis, Rehder to that of Mahonia, and Index Kewensis was the authority used for Odostemon. In certain instances reference is made to special studies, such as that of Piper (*8*). In this bulletin Berberis is considered the valid generic name for all taxonomic entities commonly classed under this genus, as well as those designated as Mahonia or Odostemon. Synonyms of doubtful validity unless otherwise specified were omitted in this bulletin.

FIGURE 1.—Young plant of *Berberis vulgaris* in condition to be inoculated with sporidia of *Puccinia graminis*. × ¾

While fully realizing that some of those that have been included may be inadequate and untenable either because of their pre-Linnaean origin or polynomial designations, it was nevertheless thought pertinent to list them on account of the possible bearing they may have on eradication measures, quarantine regulations, etc.

In taxonomic literature identical names are sometimes used for different members of Berberis. In some cases this is due to unintentional independent publication of the same name for thoroughly distinct species, in others, merely to misidentification of closely related species that may have different rust reactions. For example, *B. chinensis* Poir. is at least moderately susceptible to *Puccinia graminis*,

while *B. chinensis* Franch. is immune from stem rust. But *B. chinensis* Franch. is merely a synonym for *B. thunbergii* DC.; whereas *B. chinensis* Poir. is an authoritative name for a barberry species for which there are some 10 synonyms. In like manner, *B. brachybotrys* Edgew. (*B. edgeworthiana* Schn.) is immune from stem rust. Thus far it has not become infected as a result of artificial inoculations with *P. graminis*, nor has it, to the knowledge of the writers, ever been reported susceptible to stem rust under natural conditions. *B. brachybotrys* C. Gay, on the other hand, is listed as susceptible to stem rust by both Saccardo (*13*) and Sydow (*18*). The importance, therefore, of having a precise knowledge of the identity of a given barberry is obvious.

All the species, varieties, and hybrids of Berberis under consideration in this study, and their synonyms, are listed in alphabetical order in Table 1. In each known case the literature citation shows the source of original application. The accredited names are shown in boldface type and the synonyms in italics. In Table 1, in addition to nomenclature, reference is made to the authority responsible for the classification; to the traceable origin, or native habitat, of the organism in question; and to its known reaction to stem rust.

TABLE 1.—*Synonymy of species and varieties of Berberis and related genera, their traceable origin or native habitat, and their known reaction to stem rust*

No.	Nomenclature	Authority	Native habitat or mode of origin	Rust reaction
1	*Berberis acida* Gilib. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
2	*B. actinocarpa* Hort. (See **B. vulgaris** L.)	(*17, p. 225*)	do	Do.
3	**B. aemulans** Schn.=*B. diaphana* Schn.	(*16, p. 321*)	West Szechwan, China.	Pycnia only.
4	**B. aetnensis** Presl	(*14, p. 660*)	Sicily and Calabria, Italy.	Moderate to heavy.
5	**B. aggregata** Schn.=*B. brevipaniculata* Bean=*B. geraldii* Veitch=*B. vulgaris aggregata* Voss.	(*16, p. 295*)	East Kansu and West Szechwan, China.	Very susceptible, normal heavy infection.
6	**B. aggregata prattii** Schn.=*B. integerrima* Hort.=*B. polyantha* Hemsl.=*B. prattii* Schn.	(*16, p. 296*)	West Szechwan, China.	Light infection, pycnia only.
7	*B. alba* Poit. and Turp. (See **B. vulgaris alba** Weston.)	(*17, p. 227*)		See **B. vulgaris alba** Weston.
8	**B. alesuthensis** Hort			Very susceptible.
9	*B. altaica* Pall. (See **B. sibirica** Pall.)	(*14, p. 396*)	South Siberia; north Mongolia.	Normal infection.
10	**B. amurensis** Rupr.=*B. vulgaris* Regel=*B. vulgaris amurensis* Rupr.	(*16, p. 291*)	Chihli, China; Amur, Siberia.	Very susceptible, light to heavy infection.
11	*B. amurensis japonica* Rehd. (See **B. regeliana** Koehne.)	(*10, p. 489*)	Japan	Light to heavy infection.
12	*B. angulizans* Mass. (See **B. canadensis** Mill.)	(*17, p. 208*)	North America	See **B. canadensis** Mill.
13	**B. angulosa** Wall	(*14, p. 398*)	Himalayas	Normal infection.
14	*B. aquifolium* Lindl. (See **B. diversifolia** Steud.)	(*1, p. 296; 4, p. 292.*)	Western Pacific States; observations made in Michigan and Quebec.	See **B. diversifolia** Steud.
15	**B. aquifolium** Pursh=*B. nutkana* Kearney=*Mahonia aquifolium* Nutt.=*Odostemon nutkanus* Rydb.	(*11, p. 1970; 8, p. 450; 9, p. 164.*)	Idaho, Oregon, Washington; British Columbia.	Fruit especially heavily rusted; leaves very lightly infected.
16	*B. aquifolium fascicularis* Bean. (See **B. pinnata** Lag.)	(*11, p. 1970*)	Calif., N. Mex., Mexico.	See **B. pinnata** Lag.
17	*B. arborescens* Hort. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
18	**B. aristata** DC.=*B. aristata floribunda* Hk. and Th.=*B. chitria* Hamilt.=*B. coriaria* Royle=*B. elegans* Hort.=*B. floribunda* Lindl.	(*14, p. 451; 17, p. 204; 4, p. 292.*)	Himalayas and Nepal, India; Afghanistan.	Light infection; pustules rather small at times, though often quite large.

TABLE 1.—*Synonymy of species and varieties of Berberis and related genera, their traceable origin or native habitat, and their known reaction to stem rust*—Con.

No.	Nomenclature	Authority	Native habitat or mode of origin	Rust reaction
19	*B. aristata floribunda* Hk. and Th. (See **B. aristata** DC.)	(*14, p. 451*)	Himalayas and Nepal, India; Afghanistan.	See **B. aristata** DC.
20	*B. aristata sinensis* Koch. (See **B. chinensis** Poir.)	(*17, p. 217*)	Caucasus	See **B. chinensis** Poir.
21	*B. articulata* Loisel. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
22	**B. arvensis** Hort			Fairly susceptible.
23	**B. asiatica** Roxb.=*B. hypoleuca* Lindl.=*B. ilicifolia* Roxb.	(*14, p. 456; 10, p. 492; 4, p. 292.*)	Himalayas and Bengal, India; Afghanistan.	Moderately susceptible.
24	*B. atropurpurea* Lauche. (See **B. vulgaris atropurpurea** Regel)	(*17, p. 225*)	Garden form	Very susceptible.
25	*B. bealii* Fort. (See **B. japonica** (Thunb.) Spreng.)	(*11, p. 1971*)	China; Himalayas	See **B. japonica** (Thunb.) Spreng.
26	**B. beaniana** Schn	(*16, p. 216*)	West Szechwan, China.	Apparently immune.
27	**B. bergmanniae** Schn.=*B. bergmanniae acanthophylla* Schn.	(*16, p. 138*)	do	Moderately susceptible.
28	*B. bergmanniae acanthophylla* Schn. (See **B. bergmanniae** Schn.)	(*16, p. 138*)	China	See **B. bergmanniae** Schn.
29	*B. brachybotrys* Edgew. (See **B. edgeworthiana** Schn.)	(*15, p. 263*)	India	See **B. edgeworthiana** Schn.
30	**B. brachybotrys** C. Gay	(*4, p. 292*)	Chile	Normal infection.
31	**B. brachypoda** Maxim.=*B. brachypoda maxima* Hort.=*B. vulgaris brachypoda* Voss.	(*16, p. 285*)	Kansu, Shensi, and Hupeh, China.	Variable infection, light to heavy.
32	*B. brachypoda maxima* Hort. (See **B. brachypoda** Maxim.)	(*16, p. 285*)	China	See **B. brachypoda** Maxim.
33	**B. bretschneideri** Rehd., allied to **B. koreana** Palib.	(*10, p. 492*)	North China	Normal infection.
34	*B. brevipaniculata* Bean. (See **B. aggregata** Schn.)	(*16, p. 295*)	China	Light to heavy infection.
35	**B. brevipaniculata** Schn	(*16, p. 296*)	Hupeh, China	Infection moderate.
36	*B. brevipes* Greene. (See **B. repens** Lindl.)	(*12, p. 316*)	Pacific coast, Rocky Mountains.	See **B. repens** Lindl.
37	**B. buxifolia** Lam.=*B. dulcis* Sweet.	(*14, p. 142; 4, p. 292.*)	Chile to Strait of Magellan.	Very susceptible.
38	**B. californica** Jepson		Calif	Moderately resistant.
39	*B. canadensis* Guimp. (See **B. chinensis** Poir.)	(*17, p. 217*)	Caucasus	See **B. chinensis** Poir.
40	**B. canadensis** Mill.=*B. angulizans* Mass.=*B. canadensis* (Willd.) Pursh=*B. caroliniana* Sweet=*B. dumetorum latissimo folio* Herm.=*B. fischeri* Hort.=*B. foliis obverso-ovatis* Mill.=*B. latissimo folio canadensis* Par.=*B. mauritanica* Boer.=*B. pisifera* Raf.=*B. sinensis canadensis* Regel=*B. spinis triplicibus* Linn.=*B. vulgaris canadensis* Aiton.	(*17, p. 207; 10, p. 490; 4, p. 292.*)	Alleghenies, Ga., Mo.	Extremely susceptible, both under greenhouse conditions and in nature.
41	*B. canadensis.* (Willd.) Pursh. (See **B. canadensis** Mill.)	(*4, p. 292*)	Alleghenies	Susceptible.
42	*B. caroli hoanghoensis* Schn. (See **B. vernae** Schn.)	(*16, p. 218*)	China	See **B. vernae** Schn.
43	*B. caroliniana* Sweet. (See **B. canadensis** Mill.)	(*17, p. 208*)	Alleghenies	Susceptible.
44	*B. chinensis* Bunge. (See **B. poiretii** Schn.)	(*16, p. 227*)	China	See **B. poiretii** Schn.
45	*B. chinensis* Franch. (See **B. thunbergii** DC.)	(*17, p. 219*)	Japan	See **B. thunbergii** DC.
46	**B. chinensis** Poir.=*B. aristata sinensis* Koch=*B. canadensis* Guimp.=*B. guimpeli* Koch and Bouché=*B. iberica* Sweet=*B. intermedia* Koch=*B. serotina* Lange=*B. sinensis* Desf.=*B. spathulata* Schrad.=*B. vulgaris spathulata* Gord.	(*17, p. 216*)	Caucasus	Only moderately susceptible.
47	*B. chitria* Hamilt. (See **B. aristata** DC.)	(*14, p. 451*)	India, Afghanistan	See **B. aristata** DC.
48	*B. coerulea* Hort. (See **B. vulgaris violacea** Willd.)	(*17, p. 229*)	Garden form	See **B. vulgaris violacea** Willd.
49	**B. concinna** Hook	(*14, p. 397*)	Himalayas	Apparently immune.
50	*B. coriaria* Royle. (See **B. aristata** DC.)	(*14, p. 451*)	India, Afghanistan	Susceptible.
51	*B. coryi* Veitch. (See **B. wilsonae subcaulialata** Schn.)	(*16, p. 298*)	West Szechwan, China.	Light to heavy infection.

TABLE 1.—*Synonymy of species and varieties of Berberis and related genera, their traceable origin or native habitat, and their known reaction to stem rust*—Con.

No.	Nomenclature	Authority	Native habitat or mode of origin	Rust reaction
52	**B. crataegina** DC.	(*14, p. 657*)	Asia Minor to Persia.	Slightly susceptible.
53	**B. cretica** L.	(*14, p. 657*)	Crete; Cyprus; Greece.	Susceptible.
54	*B. cretica* Thunb. (See **B. thunbergii** DC.)	(*17, p. 219*)	Japan.	See **B. thunbergii** DC.
55	**B. declinata** Schrad.	(*17, p. 210*)	**B. canadensis**×**B. vulgaris.**	Susceptible.
56	**B. declinata oxyphylla** Schn.	(*17, p. 212*)	Hybrid form.	Very susceptible.
57	*B. dentata* Tausch. (See **B. emarginata** Willd.)	(*17, p. 193*)	**B. vulgaris**×**B. sibirica.**	See **B. emarginata** Willd.
58	**B. diaphana** Maxim.=*B. yunnanensis* Hutch.	(*16, p. 321*)	Kansu and Szechwan, China.	Moderately susceptible.
59	*B. diaphana* Schn. (See **B. aemulans** Schn.)	(*16, p. 321*)	West Szechwan, China.	See **B. aemulans** Schn.
60	**B. dictyophylla** Franch.	(*16, p. 319*)	Yunnan, China.	Moderately susceptible.
61	**B. dielsiana** Fedde.	(*16, p. 292*)	Shensi and west Szechwan, China.	Pycnial infection.
62	**B. diversifolia** Steud.=*B. aquifolium* Lindl.=*M. diversifolia* Sweet.	(*1, p. 296; 4, p. 292.*)	Western Pacific States; observations made in Michigan and Quebec.	Susceptible.
63	*B. dulcis* Sweet. (See **B. buxifolia** Lam.)	(*14, p. 142; 4, p. 292.*)	Chile.	See **B. buxifolia** Lam.
64	*B. dumetorum* Bauhin. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia.	See **B. vulgaris** L.
65	*B. dumetorum fructu candido* Mill. (See **B. vulgaris alba** Weston.)	(*17, p. 227*)		See **B. vulgaris alba** Weston.
66	*B. dumetorum latissimo folio* Herm. (See **B. canadensis** Mill.)	(*17, p. 207*)	Alleghenies.	See **B. canadensis** Mill.
67	**B. durobrivensis** Schn.	(*17, p. 206*)	**B. canadensis**×**B. poiretii.**	Moderately susceptible.
68	**B. edgeworthiana** Schn.=*B. brachybotrys* Edgew.	(*15, p. 263*)	Simla, India.	Apparently immune.
69	*B. elegans* Hort. (See **B. lycium** Royle, also **B. aristata** DC.)	(*10, p. 492; 4, p. 292.*)	Himalayas.	See **B. aristata** DC.
70	*B. elegantissima* Hort. (See **B. lycium** Royle.)		do.	See **B. lycium** Royle.
71	**B. emarginata** Willd.=*B. dentata* Tausch=*B. emarginata latifolia* Tausch=*B. vulgaris emarginata* Gord.=*B. vulgaris microphylla* Regel.	(*17, p. 193*)	**B. vulgaris**×**B. sibirica.**	Moderately susceptible in the greenhouse, normal infection in the field.
72	**B. emarginata britzensis** Schn.	(*17, p. 195*)		Infection ranges from light to heavy.
73	*B. emarginata latifolia* Tausch. (See **B. emarginata** Willd.)	(*17, p. 193*)	Hybrid form.	See **B emarginata** Willd.
74	*B. fascicularis* Sims. (See **B. pinnata** Lag.)	(*4, p. 292*)	Calif., N. Mex.; Mexico.	See **B. pinnata** Lag.
75	*B. fasciculata* Schult. (See **B. pinnata** Lag.)	(*4, p. 292*)	do.	Do.
76	**B. fendleri** A. Gray.	(*14, p. 656*)	Colo., N. Mex.; Mexico.	Very susceptible.
77	*B. fischeri* Hort. (See **B. canadensis** Mill.)	(*4, p. 292*)	Alleghenies.	Susceptible.
78	*B. floribunda* Lindl. (See **B. aristata** DC.)	(*17, p. 204*)	Nepal, India.	See **B. aristata** DC.
79	*B. foliis obverso-ovatis* Mill. (See **B. canadensis** Mill.)	(*17, p. 208*)	Alleghenies.	See **B. canadensis** Mill.
80	**B. francisci-ferdinandi** Schn.	(*16, p. 213*)	West Szechwan, China.	Light to heavy infection.
81	**B. fremontii** Torr.=*M. fremontii* Fedde=*O. fremontii* Rydb.	(*11, p. 1971; 12, p. 316; 9, p. 164.*)	West Texas to Utah, Ariz., and Calif.; Colo., Nev., and New Mexico.	Only moderately susceptible as a general rule.
82	*B. fructu albo* Mill. (See **B. vulgaris alba** Weston.)	(*17, p. 227*)		See **B. vulgaris alba** Weston.
83	*B. fructu rubro* Bobart. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia.	See **B. vulgaris** L.
84	**B. fuchsioides** Hort.=*B. fuschoides* Hort.			Susceptible.
85	*B. fuschoides* Hort. (See **B. fuchsioides** Hort.)		**B. aristata**×**B. vulgaris.**	Light to heavy infection.
86	*B. geraldii* Veitch. (See **B. aggregata** Schn.)	(*16, p. 295*)	East Kansu and west Szechwan, China.	See **B. aggregata** Schn.
87	**B. gilgiana** Fedde=*B. pubescens* Pampan.=*B. vulgaris gilgiana* Voss.	(*16, p. 285*)	Shensi and north Hupeh, China.	Moderate pycnial infection.
88	**B. glauca**=*M. glauca.* (Synonymy uncertain.)			Susceptible.

TABLE 1.—*Synonymy of species and varieties of Berberis and related genera, their traceable origin or native habitat, and their known reaction to stem rust*—Con.

No.	Nomenclature	Authority	Native habitat or mode of origin	Rust reaction
89	*B. glaucescens* Hort. (See **B. lycium** Royle.)	(*14, p. 457*)	Himalayas	See **B. lycium** Royle.
90	*B. glumacea* Spreng. (See **B. nervosa** Pursh.)	(*4, p. 292*)	Pacific coast	See **B. nervosa** Pursh.
91	*B. guimpeli* Koch and Bouché. (See **B. chinensis** Poir.)	(*17, p. 217*)	Caucasus	See **B. chinensis** Poir.
92	**B. haematocarpa** Wooton=*M. haematocarpa* Fedde=*O. haematocarpa* Heller.	(*11, p. 1971; 9, p. 178.*)	Colorado and New Mexico.	Infection ranging from light to heavy.
93	*B. hakodate* Hort. (See **B. regeliana** Koehne.)	(*10, p. 489*)	Japan	See **B. regeliana** Koehne.
94	**B. henryana** Schn	(*16, p. 292*)	West Hupeh and east Szechwan, China.	Heavy pycnial infection.
95	**B. heteropoda** Schrenk=*B. heteropoda coerulea* Regel=*B. sphaerocarpa* Kar. and Kir.	(*14, p. 457*)	Central Asia; China	Susceptible.
96	*B. heteropoda coerulea* Regel. (See **B. heteropoda** Schrenk.)	(*14, p. 457*)	do	See **B. heteropoda** Schrenk.
97	*B. heteropoda oblonga* Regel. (See **B. oblonga** Schn.)	(*14, p. 458*)	Turkestan	See **B. oblonga** Schn.
98	**B. hookeri** Lem.=*B. jamesonii* Hort.=*B. wallichiana* Hooker=*B. wallichiana latifolia* Hk. and Th.	(*16, p. 25; 10, p. 493.*)	Sikkim and Bhutan, India.	Rather slightly susceptible.
99	*B. hookeri latifolia* Bean. (See **B. xanthoxylon** Hassk.)	(*16, p. 27*)	Java	See **B. xanthoxylon** Hassk.
100	*B. horrida* Jungh.=**B. xanthoxylon** Hassk.	(*16, p. 27*)	do	Do.
101	**B. hybrida serrata** Hort			Very susceptible.
102	*B. hypoleuca* Lindl. (See **B. asiatica** Roxb.)	(*14, p. 456*)	India	See **B. asiatica** Roxb.
103	*B. iberica* Sweet. (See **B. chinensis** Poir.)	(*17, p. 216*)	Caucasus	See **B. chinensis** Poir.
104	**B. ilicifolia** Forst.=*B. serratodentata* Lechl.	(*14, p. 803*)	Chile; Uruguay; Patagonia.	Normal infection.
105	*B. ilicifolia* Roxb. (See **B. asiatica** Roxb.)	(*4, p. 292*)	Himalayas	See **B. asiatica** Roxb.
106	*B. integerrima* Hort. (See **B. aggregata prattii** Schn.)	(*16, p. 296*)	China	Susceptible.
107	*B. integerrima stenophylla* Maxim. (See **B. vernae** Schn.)	(*16, p. 218*)	West Kansu and west Szechwan, China.	See **B. vernae** Schn.
108	*B. intermedia* Koch. (See **B. chinensis** Poir.)	(*17, p. 217*)	Caucasus	See **B. chinensis** Poir.
109	*B. irritabilis* Salisbury. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
110	*B. jamesonii* Hort. (See **B. hookeri** Lem.)	(*16, p. 25; 10, p. 493.*)	India	Susceptible.
111	*B. japonica* Schn. (See **B. regeliana** Koehne.)	(*10, p. 489*)	Japan	See **B. regeliana** Koehne.
112	**B. japonica** (Thunb.) Spreng.=*B. bealii* Fort.=*M. japonica* DC.	(*11, p. 1971*)	China; Himalayas	Infection relatively light.
113	*B. javanica* Miquel. (See **B. xanthoxylon** Hassk.)	(*16, p. 27*)	Java	See **B. xanthoxylon** Hassk.
114	*B. knightii* Hort. (See **B. xanthoxylon** Hassk.)	(*16, p. 27*)	do	Infection relatively light.
115	**B. koehneana** Schn	(*14, p. 814*)	Kumaon	Light to heavy infection.
116	**B. koreana** Palib	(*10, p. 490*)	Chosen (Korea)	Moderately susceptible.
117	*B. latifolia* Poit. and Turp. (See **B. vulgaris macrocarpa** Jaeger.)	(*17, p. 228*)	Origin unknown	See **B. vulgaris macrocarpa** Jaeger.
118	*B. latissimo folio canadensis* Par. (See **B. canadensis** Mill.)	(*17, p. 207*)	Alleghenies	See **B. canadensis** Mill.
119	**B. laxiflora** Schrad	(*10, p. 493*)	Unknown origin but allied to **B. amurensis.**	See **B. amurensis.**
120	**B. leichlinii** Hort			Light to heavy infection.
121	*B. levis* Schn. (See **B. soulieana** Schn.)	(*16, p. 137*)	China	Infection rather light.
122	*B. lichtensteinii* Schn. (See **B. potaninii** Maxim.)	(*16, p. 214*)	China, north-central Provinces.	See **B. potanini** Maxim.
123	*B. lucida* Schrad. (See **B. vulgaris lucida** Gord.)	(*17, p. 226*)	Transcaucasia	Light to heavy infection.
124	**B. lycium** Royle=*B. elegans* Hort.=*B. elegantissima* Hort.=*B. glaucescens* Hort.=*B. ruscifolia* Hort.=*B. umbellicata* Hort.=*B. vulgaris elegans* Hort.	(*14, p. 457; 10, p. 493.*)	Himalayas	Wide range of infection from light pycnial to heavy aecial infection.

TABLE 1.—*Synonymy of species and varieties of Berberis and related genera, their traceable origin or native habitat, and their known reaction to stem rust*—Con.

No.	Nomenclature	Authority	Native habitat or mode of origin	Rust reaction
125	*B. macrophylla* Hort. (See **B. xanthoxylon** Hassk.)	(*16, p. 27*)	Java	Susceptible.
126	*B. mauritanica* Boer. (See **B. canadensis** Mill.)	(*17, p. 208*)	Alleghenies	See **B. canadensis** Mill.
127	*B. maxima fructu* Gerard. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
128	*B. maximowiczii* Regel. (See **B. thunbergii maximowiczii** Schn.)	(*17, p. 221*)	Garden form from seed of Japanese origin.	See **B. thunbergii maximowiczii** Schn.
129	**B. meehanii** Schn			Light to heavy infection.
130	*B. microphylla* Hort. (See **B. vulgaris** L.)	(*17, p. 225*)	Eurasia	See **B. vulgaris** L.
131	*B. microphylla serrata* Hort. (See **B. provincialis serrata** Schn.)	(*17, p. 196*)	Garden form	See **B. provincialis serrata** Schn.
132	**B. mitis** Schrad	(*4, p. 293*)		Susceptible.
133	*B. monspeliensis* Hort. (See **B. vulgaris macrocarpa** Jaeger.)	(*17, p. 228*)	Origin unknown	See **B. vulgaris macrocarpa** Jaeger.
134	**B. morrisonensis** Hayata=*B.* sp. Hayata.	(*16, p. 322*)	Taiwan (Formosa)	Infection light.
135	*B. nana* Greene. (See **B. repens** Lindl.)	(*11, p. 1970*)	Pacific coast, Rocky Mountains.	See **B. repens** Lindl.
136	*B. nepalensis* Hort. (See **B. vulgaris** L.)	(*4, p. 293*)	Eurasia	See **B. vulgaris** L.
137	**B. nepalensis** (DC.) Spreng.=*M. nepaulensis* DC.	(*10, p. 493; 11, p. 1971.*)	India, chiefly Himalayas.	Susceptible.
138	**B. nervosa** Pursh=*B. glumacea* Spreng.=*M. glumacea* DC.=*M. nervosa* Nutt.=*O. nervosus* Rydb.	(*11, p. 1971; 4, p. 292; 9, p. 164; 12, p. 316.*)	British Columbia; Idaho, Calif.	Pycnial infection only.
139	*B. neubertii* Hort. (See **B. neubertii** Lem.)	(*13, p. 176; 10, p. 492.*)	Garden form	Infection range from light to heavy.
140	**B. neubertii** Lem.=*B. neubertii* Hort.	(*10, p. 492*)	**B. vulgaris**×*M. aquifolium.*	Do.
141	**B. neubertii carolinae** Hort	(*6, p. 225*)		Susceptible.
142	**B. nevinii** A. Gray=*M. nevinii* Fedde=*O. nevinii* Abrams.	(*9, p. 164*)	Calif	Light pycnial to heavy aecial infection.
143	**B. notabilis** Schn	(*17, p. 204*)	Probably hybrid of **B. heteropoda** and **B. aristata.**	Very susceptible.
144	*B. nutkana* Kearney. (See **B. aquifolium** Pursh.)	(*8, p. 444*)	Pacific coast	See **B. aquifolium** Pursh.
145	**B. oblonga** Schn.=*B. hetereopoda oblonga* Regel.	(*14, p. 458*)	Turkestan	Very susceptible.
146	*B. officinarum* Dalechamps. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
147	**B. ottawensis** Schn	(*17, p. 221*)	**B. vulgaris**×**B. thunbergii.**	Apparently immune.
148	*B. oxyacantha.* (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
149	*B. oxyacantha galeni* Titius. (See **B. vulgaris** L.)	(*17, p. 224*)	do	Do.
150	*B. oxyacantha putata* Magnol. (See **B. vulgaris** L.)	(*17, p. 224*)	do	Do.
151	**B. parvifolia** Sprague	(*16, p. 296*)	Kansu and Szechwan, China.	Pycnial infection only.
152	*B. pedunculis racemosis* L. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
153	**B. pinnata** Lag.=*B. aquifolium fascicularis* Bean=*B. fascicularis* Sims=*B. fasciculata* Schult.=*M. fascicularis* DC.=*M. pinnata* Fedde=*O. fascicularis* Abrams.	(*4, p. 292; 9, p. 164; 11, p. 1970.*)	Calif., N. Mex.; Mexico.	Susceptible.
154	*B. pisifera* Raf. (See **B. canadensis** Mill.)	(*17, p. 208*)	Alleghenies	See **B. canadensis** Mill.
155	**B. poiretii** Schn.=*B. chinensis* Bunge=*B. poiretii weichangensis* Schn.=*B. sinensis* DC.=*B. sinensis angustifolia* Regel.	(*16, p. 226*)	Chihli and Manchuria, China.	Infection rather light.
156	**B. poiretii latifolia** Schn		China	Very susceptible.
157	*B. poiretii weichangensis* Schn. (See **B. poiretii** Schn.)	(*16, p. 226*)	do	See **B. poiretii** Schn.
158	*B. polyantha* Hemsl. (See **B. aggregata prattii** Schn.)	(*16, p. 296*)	West Szechwan, China.	Infection heavy.
159	**B. potaninii** Maxim.=*B. lichtensteinii* Schn.=*B. sphalera* Fedde.	(*16, p. 214*)	Kansu, Shensi, and northwestern Szechwan, China.	Apparently immune.
160	*B. prattii* Schn. (See **B. aggregata prattii** Schn.)	(*16, p. 296*)	Szechwan, China	Heavy infection.

TABLE 1.—*Synonymy of species and varieties of Berberis and related genera, their traceable origin or native habitat, and their known reaction to stem rust*—Con.

No.	Nomenclature	Authority	Native habitat or mode of origin	Rust reaction
161	**B. provincialis serrata** Schn.= *B. microphylla serrata* Hort.=*B. serrata* Koehne.	(*17, p. 196*)	Garden form	Moderate infection.
162	**B. pruinosa** Franch.	(*16, p. 21; 10, p. 493.*)	Yunnan, China	Light to heavy infection.
163	*B. pubescens* Pampan. (See **B. gilgiana** Fedde.)	(*16, p. 285*)	North-central China	See **B. gilgiana** Fedde.
164	*B. purpurea* Koch. (See **B. vulgaris atropurpurea** Regel.)	(*17, p. 225*)	Garden form	See **B. vulgaris atropurpurea** Regel.
165	*B. racemifera foliis ciliatis* Haller. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
166	*B. racemosa rubra* Stokes. (See **B. vulgaris** L.)	(*17, p. 224*)	do	Do.
167	**B. regeliana** Koehne=*B. amurensis japonica* Rehd.=*B. hakodate* Hort.=*B. japonica* Schn.=*B. sieboldii* Hort.=*B. vulgaris japonica* Regel.	(*14, p. 667; 15, p. 260; 10, p. 489.*)	Japan	Susceptible.
168	**B. repens** Lindl.=*B. brevipes* Greene=*B. nana* Greene=*M. brevipes* Rehd.=*M. repens* Don =*O. aquifolium* Rydb.=*O. repens* Cockerell.	(*9, p. 164; 11, p. 1970; 12, p. 316; 8, p. 460.*)	Alberta, British Columbia; Nebr., Colo., Mont., N. Mex., Calif.	Apparently immune, both under natural conditions in the field and in the greenhouse.
169	*B. ruscifolia* Hort. (See **B. lycium** Royle.)	(*10, p. 493*)	Himalayas	See **B. lycium** Royle.
170	*B. sanguinea* Koch. (See **B. vulgaris violacea** Willd.)	(*17, p. 229*)	Garden form	See **B. vulgaris violacea** Willd.
171	*B. sanguinolenta* Hort. (See **B. vulgaris** L. and **B. vulgaris violacea** Willd.)	(*17, p. 225 and 229.*)	do	Susceptible.
172	*B. serotina* Lange. (See **B. chinensis** Poir.)	(*17, p. 217*)	Caucasus	Light pycnial to moderate aecial infection.
173	*B. serrata* Koehne. (See **B. provincialis serrata** Schn.)	(*17, p. 196*)	Garden form	See **B. provincialis serrata** Schn.
174	*B. serrato-dentata* Lechl. (See **B. ilicifolia** Forst.)	(*14, p. 803*)	Uruguay to Chile	See **B. ilicifolia** Forst.
175	*B. serrulata* Raf. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
176	**B. sibirica** Pall.=*B. altaica* Pall.	(*14, p. 396*)	South Siberia; north Mongolia.	Susceptible.
177	*B. sieboldii* Hort. (See **B. regeliana** Koehne.)	(*10, p. 489*)	Japan	See **B. regeliana** Koehne.
178	**B. sieboldii** Miq.	(*14, p. 659; 10, p. 490.*)	do	Light to heavy infection.
179	*B. sinensis* DC. (See **B. poiretii** Schn.)	(*16, p. 226*)	Manchuria, China	See **B. poiretii** Schn.
180	*B. sinensis* Desf. (See **B. chinensis** Poir.)	(*17, p. 216*)	Caucasus	Light to heavy infection.
181	*B. sinensis* Koch. (See **B. thunbergii** DC.)	(*17, p. 219*)	Japan	See **B. thunbergii** DC.
182	*B. sinensis angustifolia* Mats. (See **B. thunbergii** DC.)	(*17, p. 219*)	do	Do.
183	*B. sinensis angustifolia* Regel. (See **B. poiretii** Schn.)	(*16, p. 227*)	Manchuria, China	See **B. poiretii** Schn.
184	*B. sinensis canadensis* Regel. (See **B. canadensis** Mill.)	(*17, p. 208*)	Alleghenies	See **B. canadensis** Mill.
185	**B. soulieana** Schn.=*B. levis* Schn.=*B. stenophylla* Hance.	(*16, p. 137*)	Szechwan, Shensi, and Kansu, China.	Light to moderate infection.
186	*B. spathulata* Schrad. (See **B. chinensis** Poir.)	(*17, p. 217*)	Caucasus	See **B. chinensis** Poir.
187	*B. species* Hayata. (See **B. morrisonensis** Hayata.)	(*16, p. 322*)	Taiwan	See **B. morrisonensis** Hayata.
188	*B. species* 355 Farrer			Light aecial infection.
189	*B. species* F. H. B. 59604			Light pycnial infection.
190	*B. speciosa* Hort. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
191	*B. sphaerocarpa* Kar. and Kir. (See **B. heteropoda** Schrenk.)	(*14, p. 457*)	Central Asia; China	See **B. heteropoda** Schrenk.
192	*B. sphalera* Fedde. (See **B. potaninii** Maxim.)	(*16, p. 214*)	China	See **B. potaninii** Maxim.
193	*B. spina acida sive oxyacantha* Dodon. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
194	*B. spinis triplicibus* L. (See **B. canadensis** Mill. and **B. vulgaris** L.)	(*17, p. 208 and 224.*)	Eurasia; North America.	Susceptible.
195	*B. stapfiana* Schn. (See **B. wilsonae stapfiana** Schn.)	(*16, p. 298*)	China	Light aecial infection.
196	*B. stenophylla* Hance. (See **B. soulieana** Schn.)	(*16, p. 137*)	do	See **B. soulieana** Schn.

TABLE 1.—*Synonymy of species and varieties of Berberis and related genera, their traceable origin or native habitat, and their known reaction to stem rust*—Con.

No.	Nomenclature	Authority	Native habitat or mode of origin	Rust reaction
197	*B. subcaulialata* Schn. (See **B. wilsonae subcaulialata** Schn.)	(*16, p. 298*)	West Szechwan, China.	Light to heavy aecial infection.
198	**B. swaseyi** Buckl. = *B. trifolia* Schult. = *M. swaseyi* Fedde = *O. swaseyi* Heller.	(*1, p. 296; 9, p. 178.*)	Tex. to Mexico	Light pycnial to moderate aecial infection.
199	**B. thibetica** Schn. = *B. vulgaris thibetica* Voss.	(*16, p. 224*)	West Szechwan, China.	Light to heavy infection.
200	*B. thunbergiana* Schult. (See **B. thunbergii** DC.)	(*17, p. 219*)	Japan	See **B. thunbergii** DC.
201	**B. thunbergii** DC. = *B. chinensis* Franch. = *B. cretica* Thunb. = *B. sinensis* Koch = *B. sinensis angustifolia* Mats. = *B. thunbergiana* Schult. = *B. vulgaris* Thunb.	(*17, p. 219; 14, p. 464.*)	do	Apparently immune under field conditions as well as in the greenhouse.
202	**B. thunbergii atropurpurea** Hort.		Garden form	Apparently immune.
203	*B. thunbergii dawsonii* Bean. (See **B. thunbergii minor** Rehd.)	(*17, p. 221*)	Japan	See **B. thunbergii minor** Rehd.
204	**B. thunbergii maximowiczii** Schn. = *B. maximowiczii* Regel.	(*17, p. 221*)	Garden form from seed of Japanese origin.	Apparently immune under all conditions.
205	**B. thunbergii minor** Rehd. = *B. thunbergii dawsonii* Bean.	(*17, p. 221*)	Japan	Do.
206	*B. trifolia* Schult. (See **B. swaseyi** Buckl.)	(*1, p. 296*)	Tex. to Mexico	See **B. swaseyi** Buckl.
207	*B. trifoliata* Hartw. (See **B. trifoliolata** Moric.)	(*11, p. 1971*)	do	See **B. trifoliolata** Moric.
208	**B. trifoliolata** Moric. = *B. trifoliata* Hartw. = *M. trifoliolata* Fedde = *O. trifoliolatus* Heller.	(*11, p. 1971; 1, p. 296; 9, p. 178.*)	do	Light pycnial to moderate aecial infection; rarely heavy infection.
209	**B. umbellata** Wall	(*14, p. 455; 10, p. 493.*)	Himalayas	Light to heavy infection.
210	*B. umbellicata* Hort. (See **B. lycium** Royle.)	(*14, p. 457*)	do	See **B. lycium** Royle.
211	**B. vanfleetii** Schn	(*17, p. 230*)	**B. veitchii** × **B. vulgaris.**	Light to heavy infection.
212	**B. vernae** Schn. = *B. caroli hoanghoensis* Schn. = *B. integerrima stenophylla* Maxim.	(*16, p. 218*)	West Kansu and west Szechwan, China.	Light to medium infection.
213	*B. violacea* Poit. and Turp. (See **B. vulgaris violacea** Willd.)	(*17, p. 229*)	Garden form	See **B. vulgaris violacea** Willd.
214	**B. viridis** Hort			Light to heavy infection.
215	**B. vulgaris** L. = *B. acida* Gilib. = *B. actinocarpa* Hort. = *B. arborescens* Hort. = *B. articulata* Loisel. = *B. dumetorum* Bauhin = *B. fructu rubro* Bobart = *B. irritabilis* Salisbury = *B. maximo fructu* Gerard = *B. microphylla* Hort. = *B. nepalensis* Hort. = *B. officinarum* Dalechamps = *B. oxyacantha* = *B. oxyacantha galeni* Titius = *B. oxyacantha putata* Magnol. = *B. pedunculis racemosis* Linn. = *B. racemifera foliis ciliatis* Haller = *B. racemosa rubra* Stokes = *B. sanguinoleuta* Hort. = *B. serrulata* Raf. = *B. speciosa* Hort. = *B. spina acida sive oxyacantha* Dodon. = *B. spinis triplicibus* Linn. = *B. vulgaris arborescens* Koch = *B. vulgaris canadensis* Dippel = *B. vulgaris eu-vulgaris* Briquet = *B. vulgaris heterophylla* Wierzbicki = *B. vulgaris maxima* Hort. = *B. vulgaris microphylla* Koch = *B. vulgaris normalis* Dippel = *B. vulgaris normalis typica* Regel = *B. vulgaris oblongata* Koch = *B. vulgaris obovato-oblonga* Schrad. = *B. vulgaris rubra* Alton = *B. vulgaris serotina* Jaeger = *B. vulgaris sive crespinus* Camerarius = *B. vulgaris speciosa* Jaeger = *B. vulgaris typica* Fiori = *B. vulgaris typica subrotunda* Schn. = *B. vulgo quae et oxyacantha putata* Magnol.	(*4, p. 292; 17, p. 223–225.*)	Eurasia; escaped from culture and naturalized in North America.	Extremely susceptible under nearly all conditions.

TABLE 1.—*Synonymy of species and varieties of Berberis and related genera, their traceable origin or native habitat, and their known reaction to stem rust*—Con.

No.	Nomenclature	Authority	Native habitat or mode of origin	Rust reaction
216	*B. vulgaris* Regel. (See **B. amurensis** Rupr.)	(*16, p. 291*)	Chihli, China; Amur, Siberia.	See **B. amurensis** Rupr.
217	*B. vulgaris* Thunb. (See **B. thunbergii** DC.)	(*14, p. 464*)	Japan	See **B. thunbergii** DC.
218	*B. vulgaris à fruit violet* Spach. (See **B. vulgaris violacea** Willd.)	(*17, p. 229*)	Probably hybrid	See **B. vulgaris violacea** Willd.
219	*B. vulgaris aggregata* Voss. (See **B. aggregata** Schn.)	(*16, p. 295*)	West China	See **B. aggregata** Schn.
220	**B. vulgaris alba** Weston=*B. alba* Poit. and Turp.=*B. dumetorum fructu candido* Mill.=*B. fructu albo* Mill.=*B. vulgaris flava* Schrad.=*B. vulgaris fructu albo* Kirchn.=*B. vulgaris leucocarpa* Kuntze=*B. vulgaris normalis leucocarpa* Regel.	(*17, p. 227*)		Susceptible.
221	*B. vulgaris amurensis* Rupr. (See **B. amurensis** Rupr.)	(*16, p. 291*)	Chihli, China; Amur, Siberia.	See **B. amurensis** Rupr.
222	*B. vulgaris apyrena* Hort. (See **B. vulgaris asperma** Don.)	(*10, p. 489*)		See **B. vulgaris asperma** Don.
223	*B. vulgaris arborescens* Koch. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
224	**B. vulgaris asperma** Don=*B. vulgaris apyrena* Hort.	(*10, p. 489*)		Susceptible.
225	**B. vulgaris atropurpurea** Regel =*B. atropurpurea* Lauche=*B. purpurea* Koch=*B. vulgaris foliis atropurpureis* Schueb.=*B. vulgaris foliis purpureis* Koch=*B. vulgaris normalis atropurpurea* Regel=*B. vulgaris purpurea* Bertin.	(*17, p. 225*)	Garden form	Light to heavy infection when artificially inoculated as well as under natural conditions.
226	*B. vulgaris brachypoda* Voss. (See **B. brachypoda** Maxim.)	(*16, p. 285*)	China	See **B. brachypoda** Maxim.
227	*B. vulgaris canadensis* Aiton. (See **B. canadensis** Mill.)	(*17, p. 208*)	Alleghenies	See **B. canadensis** Mill.
228	*B. vulgaris canadensis* Dippel. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
229	*B. vulgaris cyanocarpa* Kuntze. (See **B. vulgaris violacea** Willd.)	(*17, p. 229*)	Garden form	See **B. vulgaris violacea** Willd.
230	*B. vulgaris elegans* Hort. (See **B. lycium** Royle.)	(*14, p. 457*)	Himalayas	See **B. lycium** Royle.
231	*B. vulgaris emarginata* Gord. (See **B. emarginata** Willd.)	(*17, p. 193*)	Hybrid	Susceptible.
232	*B. vulgaris euvulgaris* Briquet. (See **B. vulgaris** L.)	(*17, p. 225*)	Eurasia	See **B. vulgaris** L.
233	*B. vulgaris flava* Schrad. (See **B. vulgaris alba** Weston.)	(*17, p. 227*)		See **B. vulgaris alba** Weston.
234	*B. vulgaris foliis atropurpureis* Schueb. (See **B. vulgaris atropurpurea** Regel.)	(*17, p. 225*)	Garden form	See **B. vulgaris atropurpurea** Regel.
235	*B. vulgaris foliis purpureis* Koch. (See **B. vulgaris atropurpurea** Regel.)	(*17, p. 225*)	do	Do.
236	*B. vulgaris fructu albo* Kirchn. (See **B. vulgaris alba** Weston.)	(*17, p. 227*)		See **B. vulgaris alba** Weston.
237	*B. vulgaris fructu maximo* Hornemann. (See **B. vulgaris macrocarpa** Jaeger.)	(*17, p. 228*)	Origin unknown	See **B. vulgaris macrocaroa** Jaeger.
238	*B. vulgaris gilgiana* Voss. (See **B. gilgiana** Fedde.)	(*16, p. 285*)	China	See **B. gilgiana** Fedde.
239	*B. vulgaris heterophylla* Wierzbicki. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
240	*B. vulgaris japonica* Regel. (See **B. regeliana** Koehne.)	(*10, p. 489*)	Japan	Susceptible.
241	*B. vulgaris leucocarpa* Kuntze. (See **B. vulgaris alba** Weston.)	(*17, p. 227*)		See **B. vulgaris alba** Weston.
242	**B. vulgaris lucida** Gord.=*B. lucida* Schrad.	(*17, p. 226*)	Transcaucasia	See *B. lucida* Schrad.
243	**B. vulgaris lutea** Don=*B. vulgaris xanthocarpa* Hort.	(*10, p. 489*)		Susceptible.
244	**B. vulgaris macrocarpa** Jaeger =*B. latifolia* Poit. and Turp.=*B. monspeliensis* Hort.=*B. vulgaris fructu maximo* Hornemann.	(*17, p. 228*)	Origin unknown	Do.
245	*B. vulgaris maxima* Hort. (See **B. vulgaris** L.)	(*17, p. 225*)	Eurasia	See **B. vulgaris** L.
246	*B. vulgaris microphylla* Koch. (See **B. vulgaris** L.)	(*17, p. 224*)	do	Do.

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247	*B. vulgaris microphylla* Regel. (See **B. emarginata** Willd.)	(*17, p. 193*)	Hybrid origin	See **B. emarginata** Willd.
248	**B. vulgaris nigra** Don	(*10, p. 489*)	Probably hybrid	Susceptible.
249	*B. vulgaris normalis* Dippel. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
250	*B. vulgaris normalis atropurpurea* Regel. (See **B. vulgaris atropurpurea** Regel.)	(*17, p. 225*)	Garden form	See **B. vulgaris atropurpurea** Regel.
251	*B. vulgaris normalis leucocarpa* Regel. (See **B. vulgaris alba** Weston.)	(*17, p. 227*)		See **B. vulgaris alba** Weston.
252	*B. vulgaris normalis typica* Regel. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
253	*B. vulgaris oblongata* Koch. (See **B. vulgaris** L.)	(*17, p. 224*)	do	Do.
254	*B. vulgaris obovato-oblonga* Schrad. (See **B. vulgaris** L.)	(*17, p. 224*)	do	Do.
255	*B. vulgaris purpurea* Bertin. (See **B. vulgaris atropurpurea** Regel.)	(*17, p. 225*)	Garden form	Light to heavy infection.
256	*B. vulgaris rubra* Aiton. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
257	*B. vulgaris sanguinolenta* Hort. (probably the same as *B. sanguinolenta* Hort.) (See **B. vulgaris** L. and **B. vulgaris violacea** Willd.)	(*17, p. 225 and 229.*)	Garden form	Very susceptible.
258	*B. vulgaris serotina* Jaeger. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
259	**B. vulgaris sheyalle** Hort			Light to medium infection.
260	*B. vulgaris sive crespinus* Camerarius. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
261	*B. vulgaris spathulata* Gord. (See **B. chinensis** Poir.)	(*17, p. 217*)	Caucasus	Susceptible.
262	*B. vulgaris speciosa* Jaeger. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
263	*B. vulgaris stapfiana* Voss. (See **B. wilsonae stapfiana** Schn.)	(*16, p. 298*)	China	See **B. wilsonae stapfiana** Schn.
264	**B. vulgaris sulcata** Hort			Light to heavy infection.
265	*B. vulgaris thibetica* Voss. (See **B. thibetica** Schn.)	(*16, p. 224*)	China	See **B. thibetica** Schn.
266	*B. vulgaris typica* Fiori. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
267	*B. vulgaris typica subrotunda* Schn. See **B. vulgaris** L.)	(*17, p. 225*)	do	Do.
268	**B. vulgaris violacea** Willd.=*B. coerulea* Hort.=*B. sanguinea* Koch=*B. sanguinolenta* Hort.=*B. violacea* Poit. and Turp.=*B. vulgaris à fruit violet* Spach=*B. vulgaris cyanocarpa* Kuntze.	(*17, p. 229*)	Garden form, probably hybrid between **B. vulgaris** and **B. chinensis.**	Susceptible.
269	*B. vulgaris wilsoniae* Voss. (See **B. wilsonae** Hemsl.)	(*16, p. 297*)	West Szechwan, China.	See **B. wilsonae** Hemsl.
270	*B. vulgaris xanthocarpa* Hort. (See **B. vulgaris lutea** Don.)	(*10, p. 489*)		See **B. vulgaris lutea** Don.
271	*B. vulgo quae et oxyacantha putata* Magnol. (See **B. vulgaris** L.)	(*17, p. 224*)	Eurasia	See **B. vulgaris** L.
272	*B. wallichiana* Hooker. (See **B. hookeri** Lem.)	(*16, p. 25*)	India	See **B. hookeri** Lem.
273	*B. wallichiana* Lindl. (See **B. xanthoxylon** Hassk.)	(*16, p. 27*)	Java	See **B. xanthoxylon** Hassk.
274	*B. wallichiana latifolia* Hk. and Th. (See **B. hookeri** Lem.)	(*16, p. 25*)	India	See **B. hookeri** Lem.
275	*B. wallichiana xanthoxylon* Schn. (See **B. xanthoxylon** Hassk.)	(*16, p. 27*)	Java	See **B. xanthoxylon** Hassk.
276	**B. wilsonae** Hemsl. and Wils.=*B. vulgaris wilsoniae* Voss.	(*16, p. 297*)	West Szechwan, China.	Light to heavy infection.
277	**B. wilsonae stapfiana** Schn.=*B. stapfiana* Schn.=*B. vulgaris stapfiana* Voss.	(*16, p. 298*)	Yunnan and south Szechwan, China.	See *B. stapfiana* Schn.
278	**B. wilsonae subcaulialata** Schn.=*B. coryi* Veitch=*B. subcaulialata* Schn.	(*16, p. 298*)	West Szechwan, China.	See *B. coryi*. Veitch.
279	**B. wilsonae** var. "Autumn Cheer" Hort.		Garden form	Light infection.
280	**B. wilsonae** var. "Firefly" Hort		do	Do.
281	**B. wilsonae** var. "Sparkler" Hort		do	Do.

TABLE 1.—*Synonymy of species and varieties of Berberis and related genera, their traceable origin or native habitat, and their known reaction to stem rust.*—Con.

No.	Nomenclature	Authority	Native habitat or mode of origin	Rust reaction
282	**B. xanthoxylon** Hassk.=*B. hookeri latifolia* Bean=*B. horrida* Jung.=*B. javanica* Miquel =*B. knightii* Hort.=*B. macrophylla* Hort.=*B. wallichiana* Lindl.=*B. wallichiana xanthoxylon* Schn.	(*16, p. 27*)	Java	See *B. knightii* Hort. also *B. macrophylla* Hort.
283	*B. yunnanensis* Hutch. (See **B. diaphana** Maxim.)	(*16, p. 321*)	China	See **B. diaphana** Maxim.
284	*Mahonia aquifolium* Nutt. (See **B. aquifolium** Pursh.)	(*11, p. 1970*)	Pacific coast	Susceptible.
285	*M. brevipes* Rehd. (See **B. repens** Lindl.)	(*11, p. 1971*)	Alberta to Calif.	See **B. repens** Lindl.
286	*M. diversifolia* Sweet. (See **B. diversifolia** Steud.)	(*1, p. 296*)	Western Pacific States; observations made in Mich. and Quebec.	See **B. diversifolia** Steud.
287	*M. fascicularis* DC. (See **B. pinnata** Lag.)	(*11, p. 1970*)	Calif. to Mexico	See **B. pinnata** Lag.
288	*M. fremontii* Fedde. (See **B. fremontii** Torr.)	(*11, p. 1971; 12, p. 316.*)	Nev. to Tex.	See **B. fremontii** Torr.
289	*M. glauca.*(See **B. glauca**)	(*6, p. 225; 18, p. 695.*)		Susceptible.
290	*M. glumacea* DC. (See **B. nervosa** Pursh.)	(*11, p. 1971*)	British Columbia to Calif.	See **B. nervosa** Pursh.
291	*M. haematocarpa* Fedde. (See **B. haematocarpa** Wooton.)	(*11, p. 1971*)	Colo. and N. Mex.	See **B. haematocarpa** Wooton.
292	*M. japonica* DC. (See **B. japonica** (Thunb.) Spreng.)	(*11, p. 1971*)	China; Himalayas	See **B. japonica** (Thunb.) Spreng.
293	*M. nepaulensis* DC. (See **B. nepalensis** (DC.) Spreng.)	(*10, p. 493; 11, p. 1971.*)	India, chiefly Himalayas.	See **B. nepalensis** Spreng.
294	*M. nervosa* Nutt. (See **B. nervosa** Pursh.)	(*11, p. 1971*)	British Columbia, Idaho, Calif.	See **B. nervosa** Pursh.
295	*M. nevinii* Fedde. (See **B. nevinii** A. Gray.)		Calif.	See **B. nevinii** A. Gray.
296	*M. pinnata* Fedde. (See **B. pinnata** Lag.)	(*11, p. 1970*)	Calif. to Mexico	Susceptible.
297	*M. repens* Don. (See **B. repens** Lindl.)	(*11, p. 1970*)	British Columbia to N. Mex.	Apparently immune.
298	*M. swaseyi* Fedde. (See **B. swaseyi** Buckl.)	(*1, p. 296*)	Tex. to Mexico	Moderately susceptible.
299	*M. trifoliolata* Fedde. (See **B. trifoliolata** Moric.)	(*11, p. 1971; 1, p. 296.*)	do	Slightly to moderately susceptible.
300	*Odostemon aquifolium* Rydb. (See **B. repens** Lindl.)	(*9, p. 164; 12, p. 316.*)	Alberta to Calif.	See **B. repens** Lindl.
301	*O. fascicularis* Abrams. (See **B. pinnata** Lag.)	(*9, p. 164*)	Calif. to Mexico	See **B. pinnata** Lag.
302	*O. fremontii* Rydb. (See **B. fremontii** Torr.)	(*9, p. 164; 12, p. 316.*)	Nev. to Tex.	See **B. fremontii** Torr.
303	*O. haematocarpus* Heller. (See **B. haematocarpa** Wooton).	(*9, p. 178*)	Colo. and N. Mex.	See **B. haematocarpa** Wooton.
304	*O. nervosus* Rydb. (See **B. nervosa** Pursh.)	(*9, p. 164; 12, p. 316.*)	British Columbia; Idaho, Calif.	See **B. nervosa** Pursh.
305	*O. nevinii* Abrams. (See **B. nevinii** A. Gray.)	(*9, p. 164*)	Calif.	See **B. nevinii** A. Gray.
306	*O. nutkanus* Rydb. (See **B. aquifolium** Pursh.)	(*9, p. 164*)	Pacific coast	See **B. aquifolium** Pursh.
307	*O. repens* Cockerell. (See **B. repens** Lindl.)	(*9, p. 164*)	Alberta to Calif.	Apparently immune.
308	*O. swaseyi* Heller. (See **B. swaseyi** Buckl.)	(*9, p. 178*)	Tex. to Mexico	Slightly to moderately susceptible.
309	*O. trifoliolatus* Heller. (See **B. trifoliolata** Moric.)	(*9, p. 178*)	do	See **B. trifoliolata** Moric.

BARBERRIES SUSCEPTIBLE TO PUCCINIA GRAMINIS

As stated in the introduction, information regarding susceptibility was obtained from three sources, namely, results of artificial inoculations in the greenhouse, observations of natural infections in the field and of herbarium material, and a study of records in the literature. In Table 2 those species, varieties, and garden forms are listed for which definite knowledge regarding susceptibility to stem rust is

available. The results of original inoculation experiments and direct observations, as well as references to literature, are recorded in separate columns.

TABLE 2.—*Species, varieties, and hybrids of barberry known to be more or less susceptible to stem rust* [1]

Synonymy order No.	Berberis species, varieties, and hybrids	Source of information: Original data: Results of artificial inoculation with races of Puccinia graminis: agrostidis: Number of trials	agrostidis: Successful infections	agrostidis: Relative susceptibility	avenae: Number of trials	avenae: Successful infections	avenae: Relative susceptibility	poae: Number of trials	poae: Successful infections	poae: Relative susceptibility	secalis: Number of trials	secalis: Successful infections	secalis: Relative susceptibility	tritici: Number of trials	tritici: Successful infections	tritici: Relative susceptibility	Field and herbarium observations	Literature references reporting susceptibility
3	**aemulans** Schn	1	0	?	1	0	?	1	0	?	9	1	L	2	0	?	--	
4	**aetnensis** Presl	--	--	--	1	0	?	--	--	--	29	11	H	6	5	M	+	(*13, 18*)
5	**aggregata** Schn	--	--	--	--	--	--	--	--	--	2	2	H	8	0	?	−	
6	**aggregata prattii** Schn	--	--	--	--	--	--	--	--	--	10	2	L	1	0	?	−	
8	**alesuthensis** Hort	--	--	--	1	0	?	1	1	L	13	10	H	1	1	L	+	
9	*altaica* Pall. (=**sibirica** Pall.)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(*13, 6*)
10	**amurensis** Rupr	3	2	H	--	--	--	--	--	--	8	6	M	36	32	H	+	(*13, 18, 6, 5*)
11	*amurensisjaponica* Rehd. (=**regeliana** Koehne)	--	--	--	--	--	--	--	--	--	4	1	L	1	0	?	+	
13	**angulosa** Wall	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	+	
15	**aquifolium** Pursh	1	0	?	10	0	?	3	0	?	92	35	L	39	3	L	+	(*13, 18, 6, 2, 5, 7*)
18	**aristata** DC	--	--	--	7	6	M	1	1	L	14	1	L	3	0	?	+	(*13, 18, 6, 2, 7*)
22	**arvensis** Hort	--	--	--	--	--	--	1	1	L	4	4	H	1	1	L	--	
23	**asiatica** Roxb	--	--	--	--	--	--	--	--	--	2	1	L	1	1	L	+	(*18*)
24	*atropurpurea* Lauche (=**vulgaris atropurpurea** Regel)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	+	(*6*)
27	**bergmanniae** Schn	1	0	?	--	--	--	--	--	--	3	1	M	5	0	?	--	
30	**brachybotrys** C. Gay	1	0	?	--	--	--	--	--	--	6	2	M	3	0	?	−	(*13, 18*)
31	**brachypoda** Maxim	--	--	--	--	--	--	1	0	?	18	7	M	9	2	L	−	(*7*)
33	**bretschneideri** Rehd	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	+	
35	**brevipaniculata** Schn	1	1	L	--	--	--	--	--	--	3	3	M	11	11	M	−	
37	**buxifolia** Lam	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	+	(*18, 7*)
38	**californica** Jepson	--	--	--	2	0	?	--	--	--	9	5	L	2	0	?	--	
40	**canadensis** Mill	5	5	H	1	0	?	--	--	--	14	13	H	39	34	M	+	(*1, 7*)
41	*canadensis* Pursh. (=**canadensis** Mill.)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(*13, 18, 6, 2*)
43	*caroliniana* Sweet (=**canadensis** Mill.)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	+	(*13, 18*)
46	**chinensis** Poir	--	--	--	--	--	--	--	--	--	8	0	M	6	0	?	−	(*7*)
50	*coriaria* Royle (=**aristata** DC.)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(*3*)
51	*coryi* Veitch (=**wilsonae subcaulialata** Schn.)	1	0	?	1	0	?	--	--	--	8	0	?	6	3	M	−	
52	**crataegina** DC	--	--	--	--	--	--	--	--	--	8	1	L	4	0	?	+	
53	**cretica** L	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	+	
55	**declinata** Schrad	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(*1*)
56	**declinata oxyphylla** Schn	--	--	--	1	1	L	--	--	--	7	7	H	5	4	H	+	
58	**diaphana** Maxim	--	--	--	--	--	--	--	--	--	--	--	--	6	6	M	−	
60	**dictyophylla** Franch	--	--	--	--	--	--	--	--	--	3	0	?	4	3	M	+	(*7*)
61	**dielsiana** Fedde	--	--	--	--	--	--	--	--	--	16	1	L	6	0	?	−	
62	**diversifolia** Steud	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(*1*)
67	**durobrivensis** Schn	--	--	--	--	--	--	--	--	--	6	4	M	2	1	M	+	
71	**emarginata** Willd	--	--	--	1	0	?	--	--	--	5	3	M	--	--	--	+	(*2*)
72	**emarginata britzensis** Schn	--	--	--	--	--	--	--	--	--	3	2	L	1	1	H	+	
76	**fendleri** A. Gray	--	--	--	--	--	--	--	--	--	14	12	H	4	4	M	+	(*1, 3a*)

[1] See footnote 3, p. 2.

TABLE 2.—*Species, varieties, and hybrids of barberry known to be more or less susceptible to stem rust*—Continued

Synonymy order No.	Berberis species, varieties, and hybrids	Source of information: Original data: Results of artificial inoculation with races of Puccinia graminis: agrostidis: Number of trials	agrostidis: Successful infections	agrostidis: Relative susceptibility	avenae: Number of trials	avenae: Successful infections	avenae: Relative susceptibility	poae: Number of trials	poae: Successful infections	poae: Relative susceptibility	secalis: Number of trials	secalis: Successful infections	secalis: Relative susceptibility	tritici: Number of trials	tritici: Successful infections	tritici: Relative susceptibility	Field and herbarium observations	Literature references reporting susceptibility
77	*fischeri* Hort. (=**canadensis** Mill.)																+	*(13)*
80	**francisci-ferdinandi** Schn.										7	2	M				−	
81	**fremontii** Torr.	2	2	L	2	1	L				16	11	M	6	4	L	+	
84	**fuchsioides** Hort.																+	
85	*fuschoides* Hort. (=**fuchsioides** Hort.)	2	2	H							16	14	M	4	4	L	+	
87	**gilgiana** Fedde				1	0	?	1	0	?	17	3	L	3	0	?	−	
88	**glauca**																	*(18, 6)*
92	**haematocarpa** Wooton				1	1	L				21	15	M	6	2	M	−	
94	**henryana** Schn.										6	1	L	1	0	?	−	
95	**heteropoda** Schrenk	1	0	?	1	0	?				10	1	L	2	0	?	+	*(18, 5)*
98	**hookeri** Lem.										19	1	L				+	
101	**hybrida serrata** Hort.										7	4	H	1	0	?		
104	**ilicifolia** Forst.										2	2	H				+	*(18, 6)*
106	*integerrima* Hort. (=**aggregata prattii** Schn.)																+	*(5)*
110	*jamesonii* Hort. (=**hookeri** Lem.)																+	
112	**japonica** Spreng.										18	1	L	17	0	?		
114	*knightii* Hort. (=**xanthoxylon** Hassk.)										14	3	L					
115	**koehneana** Schn.										9	2	H	2	1	L		
116	**koreana** Palib.										4	3	M				−	
119	**laxiflora** Schrad.																+	
120	**leicclinii** Hort.							1	1	L	6	6	H	14	14	M	+	*(7)*
121	*levis* Schn. (=**souliana** Schn.)										11	6	L	1	0	?		
123	*lucida* Schrad. (=**vulgaris lucida** Gord.)										5	3	M	2	1	L		
124	**lycium** Royle	1	0	?	2	2	L				15	10	M	6	1	L	+	*(6, 3, 7)*
125	*macrophylla* Hort. (=**xanthoxylon** Hassk.)																	*(13)*
129	**meehanii** Schn.										2	2	M				+	
132	**mitis** Schrad.																+	*(18)*
134	**morrisonensis** Hayata										7	3	L					
137	**nepalensis** (Thunb.) Spreng.																−	*(18, 6)*
138	**nervosa** Pursh										4	1	L	1	0	?		
139	*neubertii* Hort. (=**neubertii** Lem.)	1	1	M							4	4	H	1	1	L	+	*(13, 18, 2)*
141	**neubertii carolinae** Hort.																	*(6)*
142	**nevinii** A. Gray				1	0	?				11	5	M	1	1	L		
143	**notabilis** Schn.				1	0	?				12	11	H	2	1	H		
145	**oblonga** Schn.										9	8	H				+	
151	**parvifolia** Sprague										3	2	L					
153	**pinnata** Lag.										5	0	?	7	0	?		*(1)*
155	**poiretii** Schn.										22	2	L	7	0	?	−	
156	**poiretii latifolia** Schn.										3	1	H	1	0	?	−	
158	*polyantha* Hemsl. (=**aggregata prattii** Schn.)										3	1	H					
160	*prattii* Schn. (=**aggregata prattii** Schn.)										4	2	H				−	
161	**provincialis serrata** Schn.										1	0	?	7	7	M		
162	**pruinosa** Franch.	1	0	?	2	1	M	1	0	?	32	22	M	31	20	M	−	*(7)*
167	**regeliana** Koehne																+	
170	*sanguinea* Koch (=**vulgaris violacea** Wild.)										8	1	L					
172	*serotina* Lange. (=**chinensis** Poir.)	1	0	?	1	1	L				10	4	M	2	0	?		

TABLE 2.—*Species, varieties, and hybrids of barberry known to be more or less susceptible to stem rust*—Continued

Synonymy order No.	Berberis species, varieties, and hybrids	Source of information: Original data: Results of artificial inoculation with races of Puccinia graminis: agrostidis: Number of trials	agrostidis: Successful infections	agrostidis: Relative susceptibility	avenae: Number of trials	avenae: Successful infections	avenae: Relative susceptibility	poae: Number of trials	poae: Successful infections	poae: Relative susceptibility	secalis: Number of trials	secalis: Successful infections	secalis: Relative susceptibility	tritici: Number of trials	tritici: Successful infections	tritici: Relative susceptibility	Field and herbarium observations	Literature references reporting susceptibility
176	**sibirica** Pall.																+	(*13, 18, 6, 5*)
178	**sieboldii** Miq.										4	2	L	2	2	H	+	
180	*sinensis* Desf. (=**chinensis** Poir.)										8	5	M				+	(*18, 1*)
185	**soulieana** Schn.				1	0	?				15	3	M	2	0	?		
188	species 355 Farrer										1	1	L					
189	species F. H. B. 59604	1	0	?							2	1	L					
195	*stapfiana* Schn. (=**wilsonae stapfiana** Schn.)										4		L	1	0	?	+	
197	*subcaulialata* Schn. (=**wilsonae subcaulialata** Schn.)				1	0	?				6 6	4	M	1	0	?	+	
198	**swaseyi** Buckl.	1	0	?	3	1	L				26	20	M	4	4	L		(*1, 7*)
199	**thibetica** Schn.	1	1	H							4	3	M	2	2	L	−	
208	**trifoliolata** Moric.				2	2	L				12	12	M	22	21	L		(*1*)
209	**umbellata** Wall.	1	1	L	1	0	?				19	12	H	3	2	H		(*3*)
211	**vanfleetii** Schn.										5	4	H	2	1	M		
212	**vernae** Schn.										3	2	M	2	1	M	−	
214	**viridis** Hort.										8	6	H	1	0	?		
215	**vulgaris** L.	12	9	M	30	21	M	9	8	H	335	283	H	229	206	H	+	(*13, 18, 6, 2, 5, 1, 19, 7*)
220	**vulgaris alba** Weston																+	
224	**vulgaris asperma** Don																+	
225	**vulgaris atropurpurea** Regel										2	2	M				+	
231	*vulgaris emarginata* Gord. (=**emarginata** Willd.)																+	
240	*vulgaris japonica* Regel. (=**regeliana** Koehne)																+	
243	**vulgaris lutea** Don																+	
244	**vulgaris macrocarpa** Jaeger																+	
248	**vulgaris nigra** Don																+	
255	*vulgaris purpurea* Bertin (=**vulgaris atropurpurea** Regel.)	1	1	L							1	1	M	9	9	H	+	
257	*vulgaris sanguinolenta* Hort. (=**vulgaris violacea** Willd.)																+	
259	**vulgaris sheyalle** Hort.							1	1	M	5	4	M					
261	*vulgaris spathulata* Gord. (=**chinensis** Poir.)																+	
264	**vulgaris sulcata** Hort.				1	1	L				1	1	H	17	17	M	+	
268	**vulgaris violacea** Willd.																+	
276	**wilsonae** Hemsl.	1	1	L	2	0	?				9	6	M	13	1	M	−	
279	**wilsonae** var. "Autumn Cheer" Hort.										1	0	?	1	1	L		
280	**wilsonae** var. "Firefly" Hort.										2	1	L	1	0	?		
281	**wilsonae** var. "Sparkler" Hort.										2	2	L	1	0	?		

NOTE.—Explanation of symbols.—*Relative susceptibility*: L=light infection, M=moderate infection, H=heavy infection, ?=reaction doubtful; field observations: (+)=normal infection, (−)=no infection detected.

In the case of artificial inoculations, relative susceptibility is expressed in the terms light (L), moderate (M), and heavy (H) infection. When inoculations have thus far failed to produce infection the reaction is recorded as inconclusive, or doubtful, and symbolized

by a question mark (?). Further experiments will be necessary to prove either by positive results that the plants in question are susceptible, or by numerous negative results that they are immune. Where direct field or herbarium observations were made, the plus (+)

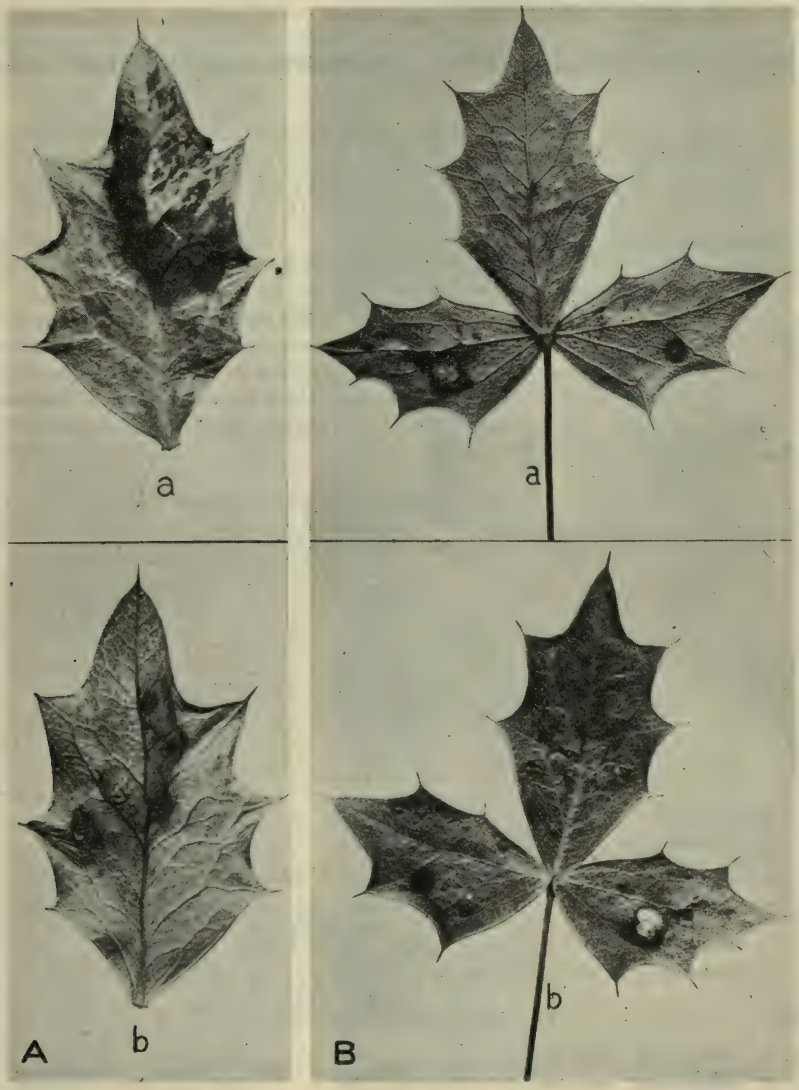

FIGURE 2.—Infection of *Puccinia graminis* on Berberis. × 2: A.—Light infection of *P. graminis tritici* on *B. fremontii: a*, Pycnia; *b*, aecia. B.—Very light infection of *P. graminis avenae* on *B. trifoliolata: a*, Pycnia; *b*, aecia

sign indicates that the plants were normally rusted, the minus sign (—) that no infection was detected.

It will be seen from Table 2 and from Figures 2 to 8, inclusive, that barberry plants differ in their reactions both as to rust races and to environmental conditions. The same barberry plant may

react differently to the same rust under differing conditions. It may also vary in its reactions to different rusts under the same conditions. Two varieties or species of barberry may also react similarly to one race of rust but may differ in their reaction to another race. Susceptibility in the barberry, therefore, is relative and is subject to biotic and climatic variations.

MEMBERS OF BERBERIDACEAE APPARENTLY IMMUNE FROM STEM RUST

In Table 3 are included those members of the barberry family which have not become infected after repeated artificial inoculations with the different parasitic races of stem rust and have never been found rusted in nature, although some of them had been under close observation for many consecutive years. While there can be no reasonable doubt that certain of the species and varieties recorded in Table 3 are immune, certain others may in the future prove to be susceptible to some race or form of *P. graminis*. This may be particularly true of those species, like *B. ottawensis* Schn., or *B. Potaninii* Maxim., which thus far have been subjected to only a limited number of tests. Yet it should be remembered that in all cases *B. vulgaris* L. was used as a check, and in each instance the latter became infected while the others did not.

TABLE 3.—*Genera and species of Berberidaceae which did not rust as a result of repeated artificial inoculations with sporidia of different varieties of Puccinia graminis and which never have been found rusted in nature*

Synonymy order No.	Hosts tested		Trials	Unsuccessful inoculation trials with Puccinia graminis varieties					Period under field observation
	Name	Synonym		agrostidis	avenae	poae	secalis	tritidi	
			No.	No.	No.	No.	No.	No.	Yrs.
26	**Berberis beaniana** Schn		17				17		
49	**B. concinna** Hook		13				13		3
68	**B. edgeworthiana** Schn	*B. brachybotrys* Edgew	18				18		
147	**B. ottawensis** Schn		6			1	5		
159	**B. potaninii** Maxim	*B. lichtensteinii* Schn., *B. sphalera* Fedde.	11			1	9	1	
168	**B. repens** Lindl	*B. brevipes* Greene, *B. nana* Greene, *M. brevipes* Rehd., *M. repens* Don, *O. aquifolium* Rydb., *O. repens* Ckrl.	53				19	34	5
201	**B. thunbergii** DC	*B. chinensis* Franch., *B. cretica* Thunb., *B. sinensis* Koch, *B. sinensis angustifolia* Mats., *B. thunbergiana* Schult.=*B. vulgaris* Thunb.	32		4		21	7	12
202	**B. thunbergii atropurpurea** Hort.		310	12		14	248	36	
204	**B. thunbergii maximowiczii** Schn.	*B. maximowiczii* Regel	47		13		24	10	3
205	**B. thunbergii minor** Rehd	*B. thunbergii dawsonii* Bean	3				3		2
	Caulophyllum thalictroides Michx.		35		11		5	19	
	Diphylleia cymosa Michx		4		1		2	1	
	Jeffersonia diphylla Pers		2					2	
	Podophyllum peltatum L		2					2	

From the results obtained it would seem safe to conclude that at least the following species are resistant to stem rust: *Berberis repens*

Lindl. (=*M. repens* Don, *O. repens* Cockerell), and *B. thunbergii* DC., with some of its horticultural varieties. It may also be safe, perhaps, to add to this group *Caulophyllum thalictroides* Michx. (Blue cohosh), *Diphylleia cymosa* Michx. (umbrellaleaf), *Jeffersonia diphylla* L. Pers. (twinleaf), and *Podophyllum peltatum* L. (mayapple). Although these plants have not been very extensively studied, the entire absence of rust in the limited number of observations and experiments made indicate immunity. Moreover, their rather distant taxonomic relationship to the genus Berberis makes it quite doubtful that they are at all susceptible to *Puccinia graminis*.

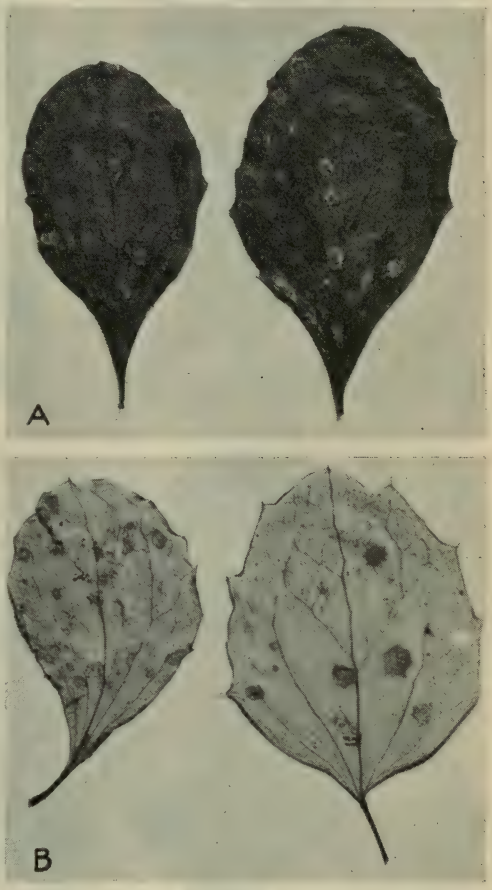

FIGURE 3.—Moderate infection of *Puccinia graminis agrostidis* on *Berberis brevipaniculata*: *a*, Pycnia; *b*, aecia. × 2

DISCUSSION AND CONCLUSIONS

Because of the importance of the barberry, not only as a carrier but also as a breeder of new and possibly dangerous rust forms, a knowledge of the range of susceptible taxonomic entities becomes absolutely necessary. One of the greatest difficulties encountered is the multiplicity of synonyms. Some of the species of Berberis are very poorly defined, and it is almost impossible to distinguish them without knowing their cultural and possible genetic origin. There are several garden forms, a considerable number of hybrids, and many closely related varieties; most of these are uniformly classified under the genus Berberis, while some of them are grouped interchangeably either as Berberis, Mahonia, or Odostemon. In this bulletin the members of all these three genera are included under the genus Berberis.

A knowledge of the authority for the different nomenclatural designations is of paramount importance. Two or more plants entirely different morphologically and physiologically may have been given the same name by different authors, e. g., *Berberis vulgaris*. There are at least three distinct plants described in literature under this name. Thus, *B. vulgaris* L. is the accredited name for the common or European barberry; *B. vulgaris* Regel is a different species of barberry and is a synonym for *B. amurensis* Rupr.; and *B. vulgaris*

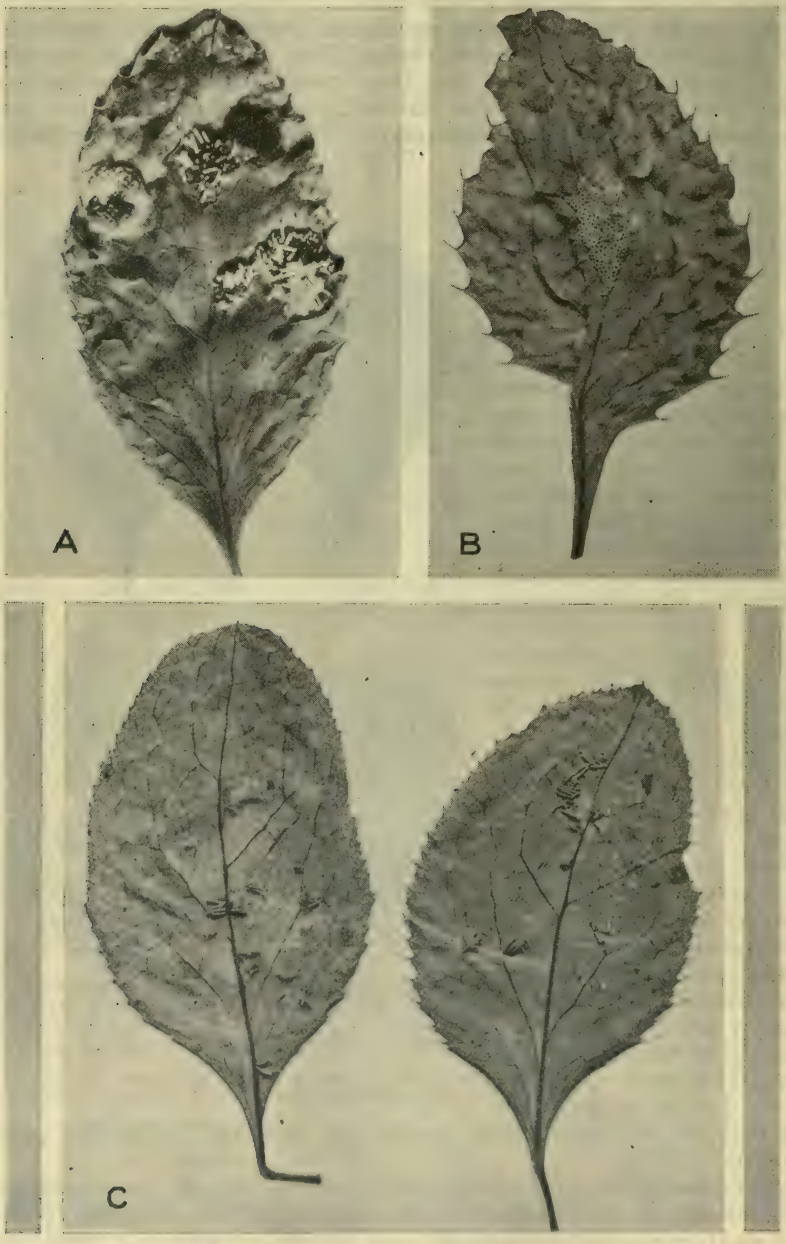

FIGURE 4.—Species of Berberis infected with parasitic races of *Puccinia graminis*. ×2. A.—*Berberis vulgaris* infected with *P. graminis poae*. (Note the long aecial cups.) B.—*B. vulgaris* infected with *P. graminis agrostidis*. (Note the relative large size of the cluster cup.) C.—*B. sieboldii* infected with *P. graminis secalis*. (Note length of aecial cups)

Thunb. is synonymous with *B. thunbergii* DC. In view of the fact that the first two are extremely susceptible to stem rust, and the last one immune from stem rust, the necessity for including the author's name in the complete name of the plant described is obvious. Unfortunately, the authority is not always known, and for this reason the author's name is omitted in a few cases cited in the tables of this bulletin.

FIGURE 5.—Pycnial infection on *Berberis asiatica* inoculated with *Puccinia graminis tritici*. The pycnia died, precluding the formation of aecia. × ¾

Information regarding the susceptibility of different barberries was obtained from a study of the literature on this subject, from extensive field observations and the examination of herbarium material, and from numerous artificial inoculations in the greenhouse. Of the six races of stem rust prevalent on this continent, namely, *Puccinia graminis tritici* Eriks. and Henn., *P. graminis avenae* Eriks. and Henn., *P. graminis secalis* Eriks. and Henn., *P. graminis poae* Eriks. and Henn., *P. graminis agrostidis* Eriks., and *P. graminis*

phleipratensis (Eriks. and Henn.) Stak. and Piem., all except the last named produced normal infection at one time or another on most of the barberries tested.

Not all the barberry hosts that harbor stem rust are under all conditions equally susceptible to this fungus. For instance, the aecia of *P. graminis tritici* and *P. graminis avenae* that developed on *Berberis fremontii* Torr. and *B. trifoliolata* Moric., respectively (fig. 2), and those of *P. graminis agrostidis* on *B. brevipaniculata* Schn. (fig. 3) were considerably smaller and readily distinguishable from those produced by *P. graminis poae* and *P. graminis agrostidis* on *B. vulgaris* L., or by *P. graminis secalis* on *B. sieboldii* Miq. (fig. 4), even when inoculated at the same time and cultured under the same conditions. This would indicate that although species like *B. fremontii* and *B. trifoliolata* may be infected with different races of *P. graminis*, they are really only slightly congenial, or in effect somewhat resistant, to the stem-rust fungus. In nature these species are seldom if ever found infected with stem rust. Some other barberry species, like *B. aemulans* Schn. or *B. asiatica* Roxb., thus far responded to artificial inoculations only to the extent of the production of pycnia which died prior to the formation of aecia. (Fig. 5.) Still other species and varieties, such as *B. canadensis* Mill., *B. declinata oxyphylla* Schn., and *B. umbellata* Wall., as a rule, checked closely with the reaction of *B. vulgaris* L. (Figs. 6, 7, and 8.)

FIGURE 6.—Sprouts of *Berberis vulgaris* infected with *Puccinia graminis secalis* showing distortion of stems, leaves, and nodes, caused by heavy infection. × ¾

Although in general those species that resemble the European barberry are susceptible to stem rust, and others resembling the Japanese barberry are resistant, it should be borne in mind that there is no absolute correlation between taxonomic characters and rust reaction. For example, hybrids between *Berberis vulgaris* L. and *B. thunbergii* DC. that have nearly all the taxonomic characters of *B. thunbergii* may

be rather susceptible. In the same way *B. neubertii* Lem., which is a hybrid between *B. aquifolium* Pursh and *B. vulgaris* L. and has some of the characters of the Mahonia, exceeds the latter in its susceptibility to rust.

FIGURE 7.—Individual leaf of *Berberis vulgaris* infected with *Puccinia graminis secalis*. × 5

Particular attention should be called to the fact that the small trailing Mahonia (*B. repens* Lindl.), so common in the mountains and foothills of the Western States in the barberry-eradication area, is evidently immune from stem rust. All attempts to infect it through artificial inoculations have failed. Neither has it been

found infected in nature. Bolley and Pritchard (*2, p. 641*) list *B. repens* among the species susceptible to *Puccinia graminis*, taking Saccardo (*13*) as their authority. But Saccardo, contrary to custom, states that *B. repens* Lindl. harbors *Aecidium berberidis* Gmel., and it is not at all clear whether he had in mind *P. graminis* or some other

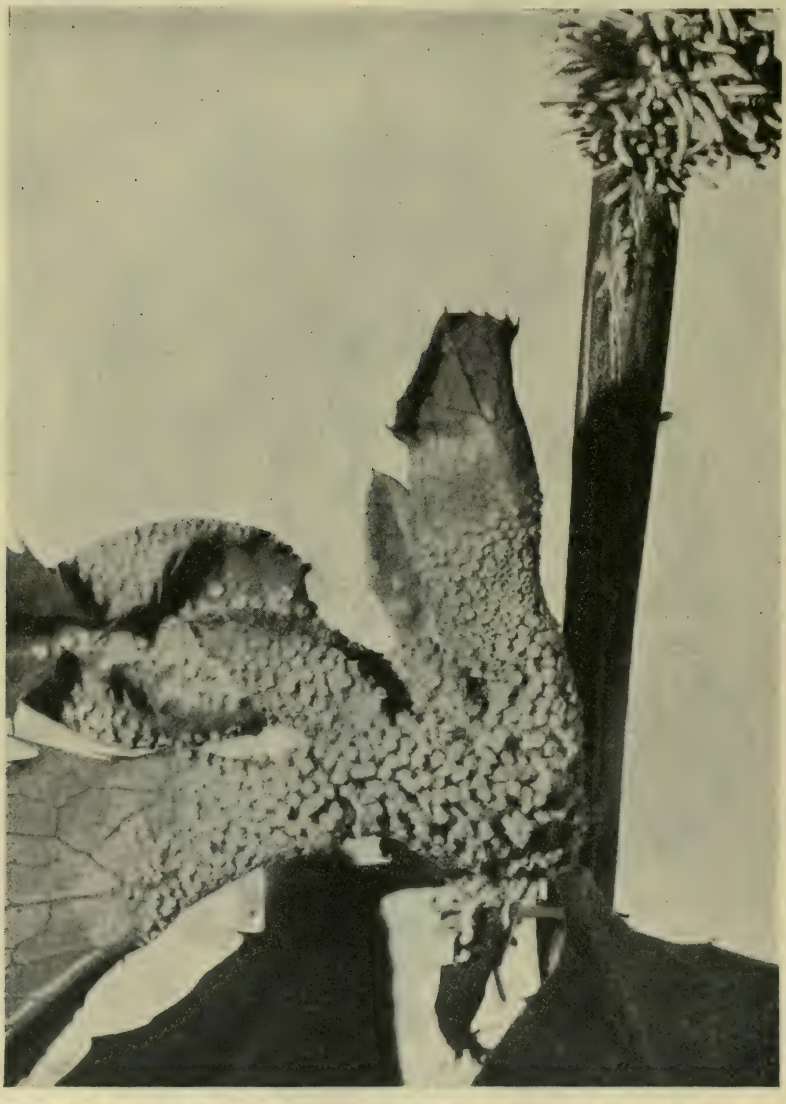

FIGURE 8.—Whorl of leaflets of *Berberis vulgaris* infected with *Puccinia graminis secalis*. Note also aecia on stem above. × 6

rust. To the writers' knowledge there is no other reference in literature that the small Mahonia is susceptible to stem rust. The tall Mahonia (*B. aquifolium* Pursh) is at least moderately susceptible to stem rust. It has been infected in the greenhouse as a result of artificial inoculations and has been found rusted under natural con-

ditions. Futhermore, according to Doctor Stakman, there are several badly rusted specimens of this Mahonia in the cryptogamic herbarium of the University of Berlin, Germany. Heavy infection on *B. aquifolium*, especially on the fruit, has been reported also from Czechoslovakia. Jaczewski (*5*) reported rusted tall Mahonia in Russia.

SUMMARY

There are slightly more than 100 established species, varieties, and hybrids of Berberis, regarding whose reaction to stem rust there is some definite knowledge. A number of these taxonomic entities have an average of three synonyms each. Some of the species of Berberis are rather ill defined, and it is almost impossible to distinguish them without knowing their cultural and genetic origin. In the present bulletin, plants that are sometimes classified as Mahonia or Odostemon are grouped under the genus Berberis.

Different authors have in some cases applied the same name to entirely different plants. Frequently these plants differ not only in botanical characteristics but also in reaction to rust. It is therefore extremely important in studying and discussing barberry plants to have the authority appended to the scientific names under review.

Information regarding susceptibility was obtained from three sources: (1) Results of artificial inoculations in the greenhouse; (2) observations of natural infections in the field and examination of herbarium material; and (3) studies of the published reports of other investigators. The artificial inoculations were made with sporidia of all the stem-rust races known in North America, and infection was obtained with all except the timothy rust. Most of the field observations were made in the Arnold Arboretum at Harvard University and in Highland Park, Rochester, N. Y. Exsiccati specimens were examined in various herbaria in this country and abroad.

Approximately 90 per cent of the accredited members within the genus Berberis, as recognized in this investigation, were susceptible in varying degrees to one or more of the parasitic races of *Puccinia graminis*. The variation in susceptibility depended on the constancy of biotic and climatic factors, such as physiologic specialization of the rust pathogene, genetic nature and age of the barberry host, prevailing atmospheric temperature, relative humidity, light intensity, etc.

Only a dozen species and varieties of Berberis seem to be immune from stem rust. Some of these may, as a result of further and more extensive experimentation, prove to be susceptible. There seems to be little doubt, however, that *B. thunbergii* DC., and *B. repens* Lindl. are actually immune.

In general, species resembling the common barberry are susceptible to stem rust, and those resembling the Japanese barberry are resistant or immune. But there are some notable exceptions. It should, therefore, be borne in mind that there is no absolute correlation between gross morphological and taxonomic characters and rust reaction. This applies also to plants commonly referred to as Mahonia. While *B. repens* Lindl., the small trailing Mahonia, evidently is immune from *Puccinia graminis*, the tall Mahonia, *B. aquifolium*, undoubtedly is susceptible, as proved both by artificial inoculations and direct observations.

LITERATURE CITED

(1) ARTHUR, J. C.
1920–1926. DICAEOMA POCULIFORME. *In* North American Flora, v. 7, p. 295–298, 775.

(2) BOLLEY, H. L., and PRITCHARD, F. J.
1906. RUST PROBLEMS: FACTS, OBSERVATIONS AND THEORIES. POSSIBLE MEANS OF CONTROL. N. Dak. Agr. Expt. Sta. Bul. 68, p. [607]–672, illus.

(3) BUTLER, E. J., and HAYMAN, J. M.
1906. INDIAN WHEAT RUSTS. India Dept. Agr. Mem., Bot. Ser. 1 (2): 1–52, illus.

(3a) DURRELL, L. W., and LUNGREN, E. A.
1926. BERBERIS FENDLERI, AN ALTERNATE HOST OF PUCCINIA GRAMINIS TRITICI. Phytopathology 16: 234–235.

(4) HOOKER, J. D., and JACKSON, B. D.
1893. BERBERIS. *In* Index Kewensis Plantarum Phanerogamarum, t. 1, p. 292–293. Oxonii.

(5) JACZEWSKI, A. VON
1910. STUDIEN ÜBER DAS VERHALTEN DES SCHWARZROSTES DES GETREIDEN IN RUSSLAND. Ztschr. Pflanzenkrank. 20: [321]–359, illus.

(6) KLEBAHN, H.
1904. DIE WIRTWECHSELNDEN ROSTPILZE; VERSUCH EINER GESAMTDARSTELLUNG IHRER BIOLOGISCHEN VERHÄLTNISSE. 447 p., illus. Berlin.

(7) MELANDER, L. W., and CRAIGIE, J. H.
1927. NATURE OF RESISTANCE OF BERBERIS SPP. TO PUCCINIA GRAMINIS. Phytopathology 17: 95–114, illus.

(8) PIPER, C. V.
1922. THE IDENTIFICATION OF BERBERIS AQUIFOLIUM AND BERBERIS REPENS. U. S. Natl. Mus. Contrib. U. S. Natl. Herbarium 20: 437–451, illus.

(9) PRAIN, D.
1913–1921. ODOSTEMON. *In* Index Kewensis Plantarum Phanerogamarum Sup. 4: 164; 5: 178. Oxonii.

(10) REHDER, A.
1914. BERBERIS. *In* Bailey, L. H., The Standard Cyclopedia of Horticulture, v. 1, p. 488–493. New York.

(11) ———
1916. MAHONIA. *In* Bailey, L. H., The Standard Cyclopedia of Horticulture, v. 4, p. 1970–1971, illus. New York.

(12) RYDBERG, P. A.
1917. FLORA OF THE ROCKY MOUNTAINS AND ADJACENT PLAINS, COLORADO, UTAH, WYOMING, IDAHO, MONTANA, SASKATCHEWAN, ALBERTA, AND NEIGHBORING PARTS OF NEBRASKA, SOUTH DAKOTA, NORTH DAKOTA, AND BRITISH COLUMBIA. 1110 p. New York.

(13) SACCARDO, P. A.
1898. BERBERIS. *In* his Sylloge Fungorum . . . v. 13, p. 174–177. Patavii.

(14) SCHNEIDER, C. K.
1905. DIE GATTUNG BERBERIS (EUBERBERIS). VORARBEITEN FÜR EINE MONOGRAPHIE. Bul. Herbier Boissier (2) 5: 33–48, 133–148, 391–403, 449–464, 655–670, 800–831.

(15) ———
1908. WEITERE BEITRÄGE ZUR KENNTNIS DER GATTUNG BERBERIS (EUBERBERIS). Bul. Herbier Boissier (2) 8: 192–204, 258–266.

(16) ———
1916–1918. WEITERE BEITRÄGE ZUR KENNTNIS DER CHINESISCHEN ARTEN DER GATTUNG BERBERIS (EUBERBERIS). Österr. Bot. Ztschr. 66: [313]–326, 1916; 67: 15–32, 135–146, 213–228, 284–300, 1918.

(17) ———
1923. NOTES ON HYBRID BERBERIS AND SOME OTHER GARDEN FORMS. Jour. Arnold Arboretum 4: [193]–232.

(18) SYDOW, P., and SYDOW, H.
1904. PUCCINIA GRAMINIS. *In* Monographia Uredinearum . . . v. 1, p. 692–698. Lipsiae.

(19) WATERHOUSE, W. L.
1921. ON THE PRODUCTION IN AUSTRALIA OF THE AECIDIAL STAGE OF PUCCINIA GRAMINIS PERS. Roy. Soc. N. S. Wales, Jour. and Proc. 55: 278–288, illus.

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REPELLENCY TO THE JAPANESE BEETLE OF EXTRACTS MADE FROM PLANTS IMMUNE TO ATTACK

By F. W. METZGER, *Associate Entomologist*, and D. H. GRANT,[1] *Agent, Division of Japanese and Asiatic Beetle Research, Bureau of Entomology*

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INTRODUCTION

A large number of plant species are apparently immune to the attack of the Japanese beetle (*Popillia japonica* Newm.), since the beetle has never been observed to attack them. These plants vary widely in habitat, structure, and physical appearance. Furthermore, to human olfaction, many of them give off strong characteristic odors, typical examples being pear, spearmint, and nasturtium. This immunity may be due to any of the factors mentioned. On the other hand, it is conceivable that the beetle may ignore them because they lack an attractive quality rather than because they possess any positive repellent characteristic.

During the course of investigations conducted to discover a repellent for the beetle, various causes of repellency were considered and, since it seemed plausible to assume that immune plants might owe their freedom from beetle attack to their content or secretion of substances toxic or distasteful to the insect, an investigation of the repellency of extracts from immune plants was undertaken.

Work on the project was begun in May, 1928, with D. H. Grant in charge of preparing the extracts and F. W. Metzger engaged in testing them in the field.[2] This arrangement continued until Mr.

[1] Resigned Oct. 1, 1929.

[2] The writers desire to express their appreciation to E. R. Van Leeuwen for his helpful suggestions, to R. J. Sim and Henry Fox for their assistance in locating and identifying various plants, and to W. W. Maines and Charles Wible for their conscientious work in the field and laboratory.

Grant resigned. The entire project was then transferred to Mr. Metzger, who carried on the work until its close in September, 1930. During the course of the investigation nearly 500 extracts were tested, which were derived from 390 species of plants. A complete botanical classified list of these plants is given at the end of this bulletin.

SELECTION OF PLANTS

At the beginning of the project it was decided to experiment with as many species of plants as possible, rather than to spend a considerable amount of time on a few. With a few exceptions, therefore, each plant was treated only once or twice in a simple manner.

All the available literature [3] was first examined to ascertain what plants were known to be immune. This information was greatly increased by the personal observations of the writers and several other members of the laboratory staff. With an extensive list of immune plants at hand, a study was then made of their habitats and abundance. The latter factor was especially important, as it had previously been determined that a supply of 2,500 to 3,000 grams of each plant would be needed for a thorough test of the resulting extract. Many species were not tested because of their small size, which would have necessitated too great an expenditure of time in collecting a sufficient quantity. Still others were discarded because, while they were relatively common, no definite knowledge as to the location of an adequate supply could be obtained.

As it was desired to include a wide range of plant genera, the most abundant species of an immune genus was selected, although in the case of particularly large genera two or more species were sometimes chosen.

Certain of the species from which extracts were desired could not be found in sufficient quantity, and in several cases a supply of the identical dried plant was purchased from a commercial source. If the same species could not be obtained, it was often possible to acquire one closely related to it that was also immune.

In some cases both the dried and the fresh plants were extracted in order to ascertain which would be the more effective. Some of the immune plants are represented on the drug market by their dried roots, which are supposed to contain their active constituents in greatest concentration. A number of drug plants not indigenous to the area infested by the Japanese beetle were also extracted, because their content of odorous or pharmacologically active principles gave hope that they might be repellent.

During the first summer in which the project was conducted, and before the necessary equipment had been obtained, a number of commercial fluid extracts of plants were purchased and tested. These extracts were chosen according to the principles just stated. The commercial vegetable dyeing and tanning materials were employed to ascertain whether or not any of the readily available commercial plant products would be repellent to the beetle rather

[3] SMITH, L. B., and HADLEY, C. H. THE JAPANESE BEETLE. U. S. Dept. Agr. Circ. 363, 66 p., illus. 1926.
SAFRO, V. I. SOME ORNAMENTAL TREES AND SHRUBS PRACTICALLY FREE FROM JAPANESE BEETLE ATTACKS. N. J. Dept. Agr. Circ. 133, 6 p. 1928.
——— SOME GARDEN ORNAMENTALS PRACTICALLY UNHARMED BY JAPANESE BEETLES. N. J. Dept. Agr. Circ. 134, [2] p. 1928.
——— SOME FARM CROPS PRACTICALLY FREE FROM JAPANESE BEETLE ATTACK. N. J. Dept. Agr. Circ. 136, [3] p. 1928.

than because these extracts were prepared from plants known to be immune to beetle attack.

Many of the cultivated plants were grown on the laboratory grounds, as they could not usually be collected from private fields or gardens. Most of the wild plants were collected within a radius of a few miles from the laboratory, which is situated several miles from the heavily populated Philadelphia and Camden areas.

METHODS EMPLOYED IN EXTRACTING PLANTS

DRY MATERIAL

The directions contained in the United States Pharmacopœia, tenth edition (process for fluid extracts), were followed, except that the total percolate was used without distillation. The volume of solvent used was adjusted so that about four times as many cubic centimeters of total percolate were obtained as there were grams of dried plant. Most dried plants retain about as many cubic centimeters of solvent as there are grams of plant. Thus, in order to obtain the required amount of percolate, it is necessary to use five times as many cubic centimeters of the solvent as there are grams of the plant.

The entire amount of solvent was prepared at one time and one-fifth of it poured over the plant and thoroughly stirred. The mass was kept in a closed container and allowed to macerate for eight hours at room temperature. It was then packed in a percolator, at least an inch of space being left at the top, and a sheet of filter paper was laid upon the surface to prevent channeling by the stream of solvent. The solvent was added until it began to filter through the cotton at the bottom of the percolator, when a cork was inserted to stop the flow. The material was then allowed to macerate for 48 hours, care being taken that the solvent always stood at least an inch above the filter paper. At the expiration of this period the cork was withdrawn and percolation begun. The remainder of the solvent was then placed in a bottle inverted over the top of the percolator, so that the mouth of the bottle was well within the percolator and a short distance above the filter paper. This allowed the solvent to trickle into the percolator as fast as it ran out at the lower end.

Pharmacopœial fluid extracts are reduced to a concentration at which each cubic centimeter of extract represents the useful principles extracted from 1 gram of dried plant. In the percolation process the first 100 c. c. of the percolate are usually reserved. Alcohol is then recovered from the remainder of the percolate, which is then concentrated at a temperature not exceeding 60° C. The extract is then dissolved and mixed in the reserve portion, after which sufficient menstruum is added to make the extract measure 1,000 c. c. As the extracts made by the writers were not concentrated by recovering the alcohol and by distillation, they were usually of such a strength that 4 c. c. represented 1 gram of dry plant material.

Dilutions of extracts for application in the field were always calculated to a basis of one part of original dry plant to so many parts of spray. For example, in the accompanying tables a dilution of "1/25" means that each 25 liters represents 1 kilogram of original dry plant. Such a solution would usually be prepared by taking 4 liters of an extract resulting from a percolation, as described above, and diluting it with water to make 25 liters.

FRESH MATERIAL

The following method for extraction of fresh plants was devised after considerable experimental work with various processes and types of apparatus. It has been found very satisfactory in making nearly all the extracts.

In cutting the fresh plant a machine (fig. 1) was employed such as is used in hotels and restaurants for chopping cabbage, onions, celery, etc. It consists of a pair of rapidly rotating knives in a bowl which constantly turns so as to bring the material repeatedly under the knives. This machine is operated by a motor and works equally well with leaves, flowers, and practically all parts of plants except the tough woody stems. The material was placed in the cutter and chopped as finely as possible. Not more than 10 minutes was allowed for each batch, however, as the material became warm after that period, and there was danger of loss through oxidation and volatilization.

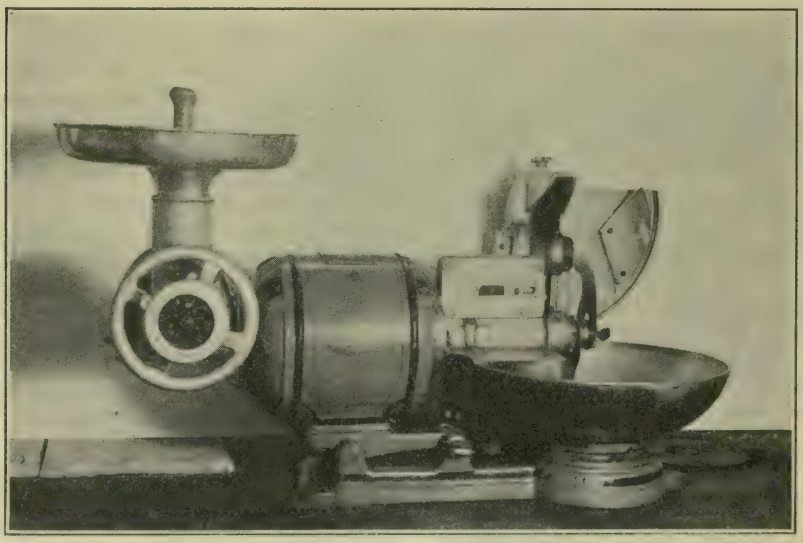

FIGURE 1.—Machine used to cut fresh plants

The chopped material was placed in a container and weighed. As many cubic centimeters of solvent were added as there were grams of plant. The mass was then thoroughly stirred, tightly covered, and allowed to stand overnight. The next morning the material was extracted in a centrifuge (fig. 2) having a perforated cylindrical bronze basket 11 inches in diameter. This basket, as well as the receiver surrounding it, was silver-plated to prevent reaction of acid plant juices with the bronze. The basket was first lined with muslin to prevent the holes in its sides from becoming clogged by the plant and then the material was loaded evenly into it. The centrifuge was speeded up to 3,000 revolutions per minute and allowed to run until only a few drops of the extract ran out during a minute's time. It was then slowed down considerably, and 100 c. c. of solvent was poured into the basket by directing the stream on the shoulder of the bearing within, thereby scattering the solvent fairly uniformly over

the material. The centrifuge was stopped for one minute and then again run at its former speed until the drops ran out slowly. This washing process was usually repeated four times.[4]

It was assumed that most fresh plants lose about 75 per cent of their weight on drying; therefore, an extract made from a fresh plant

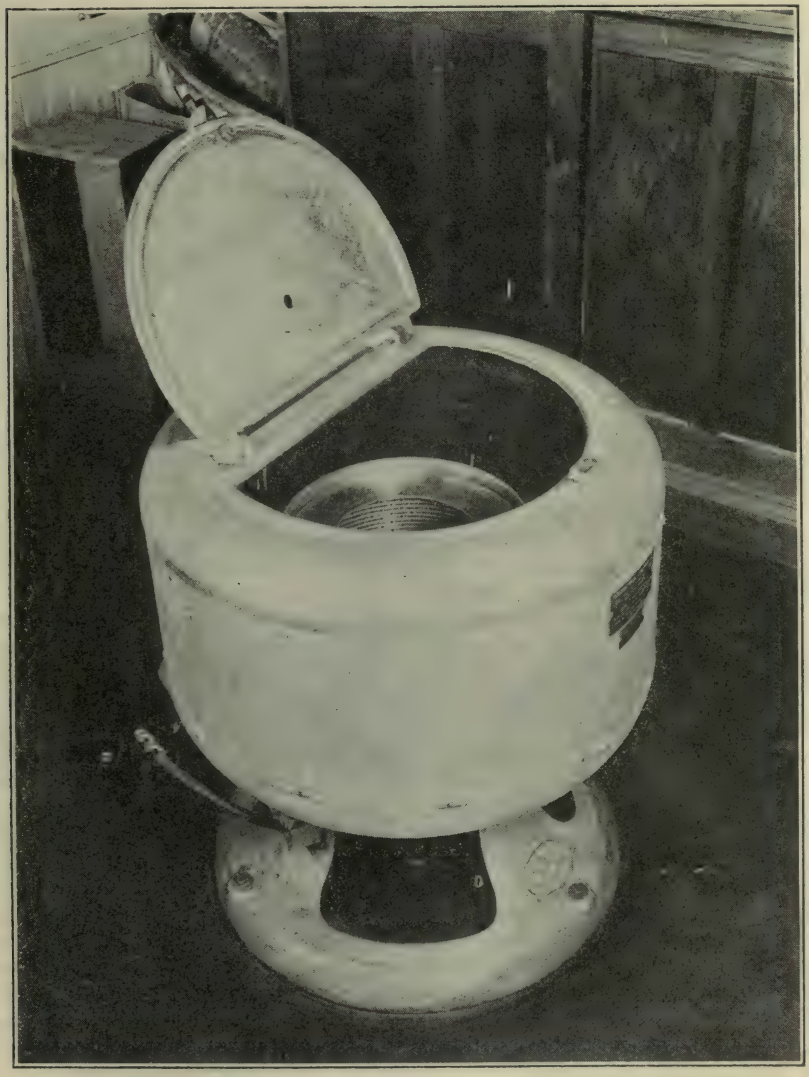

FIGURE 2.—Centrifuge employed in plant extraction

was usually considered to be one-fourth as strong as an extract of the same volume made from the same weight of plant in a dried condition. An illustration of the method of reducing the quantity of extract from a fresh plant to terms of that from a dried plant

[4] JUILLET, A. LE PYRÈTHRE INSECTICIDE DE DALMATIA. ORIGINE, CULTURE, PRINCIPES ACTIFS, APPLICATIONS À L'AGRICULTURE. 236 p., illus. Montpellier, 1924.

follows: 4,000 c. c. of extract are obtained from 3,000 grams of fresh plant or 750 grams of dried plant; therefore, 5.3 c. c. of this extract represents 1 gram of dried plant. All extracts from fresh plants were applied on this basis.

SOLVENTS

In an intensive study of a few plant extracts it is desirable that each plant be treated with several solvents and in as many ways as possible in order to insure a complete extraction of all active principles. Unlimited work could be done on a single plant if an effort were made to isolate and test all possible individual constituents. When, however, it is intended to examine a wide range of plants in a comparatively short time, such a course becomes impracticable and a fairly simple, uniform treatment must be accorded each plant.

Certain of the fresh plants mentioned in this paper, such as potato, tobacco, and tomato, were treated with several solvents, and the resulting extracts, representing different classes of plant constituents, were tested separately. Most of the plant species, however, were treated with only one solvent. After careful consideration it was decided that more of the active plant principles could probably be extracted by the use of alcohol, or alcohol and water, than by any other solvent. These two agents were employed almost exclusively on fresh plants. Ethyl alcohol, 95 per cent, was used at full strength on a large number of plants, and the same solvent diluted 50 per cent with water on others.

Many of the dried plants that were extracted are used in medicinal preparations, and the solvents used on these plants were in accordance with the indications given in the United States Dispensatory, Wood and LaWall, twenty-first edition.

It is believed that the extractions were reasonably complete as regards alcohol-soluble constituents of the plants. Since such constituents include all the essential oils and most resins, glucosides, and alkaloids, it is evident that the method used probably yielded an extract containing all the substances from each plant which were most likely to possess repellency, with the exception of toxic proteins.

As the exact nature of the repellent principles contained in each plant was unknown, it was deemed advisable to test the extracts without recovering the alcohol. Distillation, even under reduced pressure, might carry off certain substances, such as essential oils, which should be retained in the extracts, besides entailing the danger of thermal decomposition or polymerization of unstable organic substances. The presence of the alcohol in the extracts was not considered objectionable in field tests, as ethyl alcohol at full strength is only slightly attractive to the beetle. It was never present in the diluted extracts at more than a 5 per cent concentration and soon evaporated when applied in spray form. The same may obviously be true of the more volatile portions of the plant extractives.

EXPERIMENTAL PROCEDURE IN THE FIELD

Most of the extracts were tested on small peach and apple trees of several varieties, and on larger peach trees of the Early Rose variety. The small trees were employed during 1929 and 1930 and bore no fruit during either year, not having reached the bearing age. The

large trees were used for three summers; they had a fair crop of fruit in 1928 and 1929, but very little in 1930 because of adverse climatic conditions. Each of the large trees required 3 gallons of spray per application, the smaller peach trees from 1 to 1½ gallons, and 2 quarts of spray were necessary for the apple trees. One or two of the large trees and two or three of the small ones were used in each test. When rain followed a treatment before the desired data were obtained, a second, and sometimes a third, application was made in order that observations might be taken while the substance was at its maximum strength.

A few tests were conducted on corn, on roses, and on smartweed in cages. The corn, which was in silk, was treated by pouring the extracts directly over the tops of the ears so that the silk became thoroughly drenched.

The degree of infestation at the time each test was begun was estimated according to the criteria given in Table 1. After an extract was applied the number of beetles present on the treated trees was observed at intervals of not more than 24 hours. Numerous check trees, located in all parts of the experimental orchards so that the infestation of each treated tree could be compared with that of an untreated tree in its immediate vicinity, were observed at like intervals. The checks were sprayed with water at the time a test was begun, but otherwise they were untreated. The observations were continued as long as a material showed any repellency, or as long as was necessary to obtain an indication of the value of the extract.

TABLE 1.—*Criteria employed in estimating infestation*

Infestation	Number of beetles per tree on—		
	Apple trees	Small peach trees	Large peach trees
Very light		0 to 10	0 to 25.
Light	0 to 5	11 to 25	26 to 100.
Moderate	6 to 20	26 to 100	101 to 250.
Heavy	Over 20	Over 100	Over 250.

The sprays were applied with a bucket pump in 1928 and 1929. During 1930 a small power spray outfit (fig. 3) was employed, and a much better coating was obtained.

In working with the Japanese beetle, one of the greatest difficulties encountered is the brevity of the period in which field tests can be conducted. During the three summers in which this work was in progress accurate results could be obtained only between July 1 and August 15.

RESULTS

A complete report of all the materials tested is too voluminous to be included in this bulletin. The greater number of the extracts gave no indications of being repellent to the beetle, and such extracts are merely listed in the botanical classification (Table 4), together with the respective solvents and the dilution rate. The extracts which were repellent to any extent are discussed in the following paragraphs.

REPELLENCY AFTER HEIGHT OF BEETLE SEASON

The following plant extracts, when applied on one large, moderately infested peach tree just after the height of the beetle season, exhibited repellent qualities:

Material	Dilution
Comandra (*Comandra umbellata* (L.) Nutt.)	1/25
Common rue (*Ruta graveolens* L.)	1/25
Gerardia (*Aureolaria pedicularia* (L.) Raf.)	1/25
Hawkweed (*Hieracium pratense* Tausch.)	1/30
Jersey-tea (*Ceanothus americanus* L.)	1/30
Kentucky coffeetree (*Gymnocladus dioica* (L.) Koch.) (light infestation)	1/35
Pinus sp. (needles)	1/50
Shepherd's-purse (*Bursa bursa-pastoris* (L.) Britton)	1/25
Swamp-pink (*Helonias bullata* L.)	1/25
Thoroughwort (*Eupatorium hyssopifolium* L.)	1/40
Unifolium canadense (Desf.) Greene	1/30

FIGURE 3.—Outfit used in applying plant extracts during 1930

None of the extracts tested in this orchard while the infestation was increasing proved to be even slightly repellent, and it is questionable whether any of these 11 extracts would have shown repellent qualities had they been tested earlier in the season.

The repellency of these substances, moreover, was not so strongly marked as that exhibited by derris and pyrethrum-powders used at the rate of 3 pounds to 50 gallons of water and applied at the same time as the extracts.

Further tests with these domestic plant extracts before the height of the beetle season will be necessary in order definitely to establish their repellent value.

REPELLENCY ON CORN

Ten extracts tested separately at full strength on corn reduced infestation 40 to 76 per cent. (Table 2.) The corn was treated near the end of the beetle season in 1930, when the insect was becom-

ing less numerous, and on three check plots where water was poured on the ears the infestation decreased 18 per cent in 24 hours. This factor was considered when computing the degree of repellency on the treated plots, which in each case was 18 per cent greater than indicated in the table. All the extracts except coreopsis included in Table 2 burned the husks severely, probably because of the alcohol they contained, but this is not believed to have influenced the results, as many other extracts which also caused serious burning showed no repellency. Although the burned husks had a dried appearance, an examination of a large number of ears revealed that the effect on the kernels was apparently negligible.

TABLE 2.—*Plant extracts repellent on corn when given one application at full strength on heavily infested ears*

Material	Ears treated	Repellency 24 hours after application	Ears burned 24 hours after application
	Number	*Per cent*	*Per cent*
Afghan blistercress (Erysimum perofskianum Fisch. and Mey.)	43	40	60
Black-eyed-susan (Rudbeckia hirta L.)	62	56	60
Blueberry (Vaccinium sp.)	15	54	100
Chiretta (Swertia chirayita (Roxb.) Lyons)	60	62	70
Cocillana (Guarea rusbyi (Britton) Rusby)	39	69	100
Common prickly-ash (Zanthoxylum americanum Mill.)	56	76	90
Coreopsis (Coreopsis grandiflora Hogg.)	19	60	0
Hickory (Hicoria sp.)	61	58	75
Horseweed (Erigeron canadensis L.)	92	68	66
Redroot (Gyrotheca tinctoria (Walt.) Salisb.)	20	50	5

The extracts of horseweed, cocillana, and common prickly-ash were the most effective repellents on corn. Horseweed and prickly-ash were also effective when applied at a dilution of 1/25 on small apple trees.

COMMERCIAL EXTRACTS USED IN DYEING AND TANNING

The following commercial vegetable extracts which are used in the dyeing and tanning industries also gave effective repellency when applied in a 1/25 dilution on two occasions on a large peach tree that was bearing fruit at the time of application:

Material	Character of residue
American chestnut (*Castanea dentata* (Marsh.) Borkh.)	Light.
Black oak (quercitron) (*Quercus velutina* Lam.)	Dark colored.
Divi-divi (*Caesalpinia coriaria* Willd.)	Heavy.
Fustic (*Chlorophora tinctoria* (L.) Gaud.)	Bright yellow.
Gallnut (*Quercus* spp.)	Yellow.
Gambier (*Ourouparia gambia* (Hunter) Baillon)	Brown.
India-almond (*Terminalia catappa* L.)	Light.
Logwood No. 1 (*Haematoxylon campechianum* L.)	Heavy brown.
Logwood No. 2 (*Haematoxylon campechianum* L.)	Do.
Osage-orange (*Toxylon pomiferum* Raf.)	Do.
Quebracho (*Schinopsis* sp.)	Do.
Sydney wattle (*Acacia longifolia* Willd.)	Brown.
Valonia (*Quercus* spp.)	Light colored.

All these substances left a conspicuous residue, which probably accounts for their repellent action. The residues from fustic, logwood No. 1, black oak, valonia, and wattle extracts possessed excellent

sticking qualities and remained on the fruit longer than any of the other commercial extracts mentioned.

There was sufficient rain, however, just before the fruit was harvested to remove most of this residue, and there was no loss in marketable fruit that could be attributed to the treatment.

New Jersey dry mix, which consists of sulphur 8 parts, hydrated lime 4 parts, and calcium caseinate one-half part, was applied at the rate of 12½ pounds to 50 gallons of water under the same conditions as were the extracts, and its use resulted in excellent protection to fruit and foliage. This material was more effective as a repellent than any of the extracts which have been tested.

EXTRACTS REPELLENT AT FULL STRENGTH BUT NOT AT 1/25 DILUTION

Several other extracts were repellent when employed at full strength but were ineffective when used in diluted form. Included in this group are the extracts of black-eyed-susan, coreopsis, castor-bean plant, sweetbay, cocillana, hickory, holly, and redroot. It would be impracticable to use these materials at full strength as a control measure, but as the only other concentration employed was 1/25, it appears that some repellency might be obtained at a concentration between these two extremes.

Extracts of goldenrod and *Aureolaria pedicularia* were repellent when used at 1/25 on peach and apple trees, respectively, but were not repellent at full strength on corn. The corn, however, was heavily infested when the treatments were made, whereas the infestation on the fruit trees was negligible. It is well known that a stronger repellent is needed to reduce an infestation of the Japanese beetle than is required to prevent one.

EXTRACTS REPELLENT ON SMALL PEACH AND APPLE TREES

Twenty-two extracts tested on small peach or apple trees gave indications of being more or less effective repellents. (Table 3.) Horseweed, chiretta, and prickly-ash extracts were also repellent on corn. Goldenrod extracts, also tested on corn, were not repellent. Aloe extract, when used at full strength on smartweed in cages, did not prevent extensive feeding. Common box was tested on both apple and peach trees. The other 16 materials in this group—namely, bearberry, betony, black oak, Christmas-rose, comfrey, false-hellebore, fennel-flower, holly, mayapple, New England aster, pimpinella, purple trillium, rosemary (flowers), springbeauty, sweetbay, and white turtlehead—were tested on only one kind of foliage. The tests with these extracts were by no means extensive enough to warrant the results being considered more than preliminary in nature.

TABLE 3.—*Extracts repellent on small peach and apple trees*

Material	Dilution	Number and kind of trees	Infestation at first application	Number of applications
American holly (Ilex opaca Ait.)	1/25	2 apple	None	1
Bearberry (Arctostaphylos uva-ursi (L.) Spreng.)	1/25	2 peach	Very light	2
Black oak (Quercus velutina Lam.)	1/25	2 apple	None	2
Chiretta (Swertia chirayita (Roxb.) Lyons)	1/25	do	do	2
Christmas-rose (Helleborus niger L.)	[1] f. s.	3 apple	Light	1
Common betony (Stachys officinalis (L.) Franch.)	1/25	2 peach	Very light	2
Common box (Buxus sempervirens L.)	1/50	1 peach	Moderate	2
Do	1/50	1 apple	do	2
Common comfrey (Symphytum officinale L.)	1/25	2 peach	None	2
Common mayapple (Podophyllum peltatum L.)	1/25	do	do	1
Common prickly-ash (Zanthoxylum americanum Mill.)	1/25	2 apple	do	1
False-hellebore (Veratrum album L.)	1/25	3 apple	do	3
Fennel-flower (Nigella sativa L.)	f. s.	do	Moderate	1
Goldenrod (Solidago sp.)	1/25	2 apple	None	2
Horseweed (Erigeron canadensis L.)	1/25	do	do	1
New England aster (Aster novae-angliae L.)	1/25	do	do	2
Pimpinella (Pimpinella saxifraga L.)	f. s.	do	do	1
Purple trillium (Trillium erectum L.)	1/25	2 peach	do	2
Rosemary (flowers) (Rosemarinus officinalis L.)	1/25	2 apple	do	2
Sweetbay (Magnolia virginiana L.)	f. s.	do	do	1
True aloe (Aloe vera L.)	1/25	2 peach	do	2
Virginia springbeauty (Claytonia virginica L.)	1/25	2 apple	do	2
White turtlehead (Chelone glabra L.)	1/25	2 peach	do	2

[1] f. s.=full strength.

MISCELLANEOUS

Winterberry extract (*Ilex paraguariensis* St. Hil.), applied twice at a dilution of 1/25 on a large peach tree lightly infested at the time of the first application, and castor-bean extract (*Ricinus communis* L.), applied at full strength on smartweed in cages upon which beetles fed but lightly, also showed some repellency to the Japanese beetle.

SUMMARY AND CONCLUSIONS

During the three years in which this project was conducted, 474 extracts, representing 390 plant species, were tested. These 390 plants were taken from 326 genera and 108 families. Several extracts were made from tomato, tobacco, and potato, and certain other plants were extracted in both the fresh and dry states. Although the number of immune plants has by no means been exhausted, it is believed that a fairly comprehensive survey has been made.

Only 56 extracts gave any indication of repellency. Thirteen of these were commercial extracts which probably repelled because of a conspicuous residue deposited on the foliage. Other white materials, such as lime and the New Jersey dry mix, repelled equally as well.

The repellent value of 11 other extracts was doubtful, as they were applied after the peak of the beetle season and were not subjected to such a severe test as were many of the other extracts. The repellency of these materials was much less than that shown by powdered derris and pyrethrum applied in spray form at the rate of 3 pounds to 50 gallons of water.

Ten extracts, each used at full strength on corn, were repellent, but only three were of possible value. All three burned the husks severely. In addition, the use of a plant extract at full strength would be too costly to be practical as a control measure.

Of the 22 extracts showing repellency on small peach and apple trees, 15 were repellent on small apple, 6 on small peach trees, and 1 on small peach and small apple trees. One extract showed some re-

pellency on smartweed in cages, and 1 on a large peach tree. Three extracts were repellent on both corn and apple.

The writers believe that the only extracts which might be tested more extensively with profit are those listed under "Extracts repellent on small peach and apple trees." Further work could be conducted with extracts of plant species not yet tested, but as the more abundant and important immune plants have been extracted, it is doubtful whether a continuation of this investigation would result in the discovery of a practical repellent for the Japanese beetle.

BOTANICAL CLASSIFICATION OF PLANTS EXTRACTED

A botanical classification of all plants extracted is given in Table 4. The solvent used and plant part employed are listed for each extract. Families are arranged in alphabetical order.

TABLE 4.—*Botanical classification of plants extracted, together with solvent, part used, and rate of application*

[Key to abbreviations: a, alcohol; ac, acetic acid; an, acetone; b, benzol; c, chloroform; g, glycerin; p, petroleum ether; pn, petroleum naphtha; w, water; f. s., full strength]

Family and scientific name	Common name	Solvent	Part used	Dilution
Aceraceae:				
Acer rubrum L.	Red maple	a	Fresh leaves	1/25
Acer saccharinum L.	Silver maple	a	do	1/30
Amaranthaceae: Amaranthus retroflexus L.	Pigweed	a	Fresh leaves and stalks	1/25
Amaryllidaceae: Narcissus pseudonarcissus L.	Common daffodil	a	Fresh, entire plant in flower.	1/25
Anacardiaceae:				
Rhus glabra L.	Smooth sumac	a	Fresh leaves and fruit	1/50
Do.	do		N. F. extract	1/64
Rhus sp.	Sumac		2 commercial extracts	1/25
Rhus aromatica Ait.	Fragrant sumac	a–w	Dry bark	1/25
Apiaceae:				
Angelica archangelica L.	Angelica		N. F. extract	1/64
Cicuta maculata L.	Spotted waterhemlock	a	Fresh leaves and flowers	1/50
Conium maculatum L.	Poison hemlock	a	Dry fruit	1/35
Do.	do	a–w–ac	do	1/25
Daucus carota L.	Common carrot	a	Fresh entire plant in flower.	1/50
Do.	do	a–w	do	f. s.
Foeniculum vulgare Hill.	Common fennel	a–w	Dry seed	1/25, f. s.
Imperatoria ostruthium L.	Masterwort	a	Dry root	1/25
Pastinaca sativa L.	Parsnip	a	Fresh leaves and tops	1/25
Pimpinella anisum L.	Anise	a–w	Dry fruit	1/50
Pimpinella saxifraga L.	Pimpinella	a–w	Dry rhizome and root	1/25
Sium laeve Walt.	Waterparsnip	a	Fresh entire plant in flower.	1/25, f. s.
Apocynaceae:				1/64
Apocynum cannabinum L.	Hemp dogbane		N. F. extract	
Do.	do	a	Dry rhizome and root leaves.	1/25
Apocynum androsaemifolium L.	Spreading dogbane	a	Fresh pods	1/50
Do.	do		U. S. P. extract	1/64
Schinopsis sp.	Quebracho		Commercial extract	1/25
Strophanthus kombe Oliver.	Strophanthus		U. S. P. extract	1/125
Aquifoliaceae:				
Ilex opaca Ait.	American holly	a	Fresh leaves	1/25, f. s.
Ilex paraguariensis St. Hil.	Paraguay-tea	a–w	Dry leaves	1/25
Ilex verticillata (L.) A. Gray.	Common winterberry	a–w	Dry bark	1/25
Araceae:				
Acorus calamus L.	Sweetflag	a–w	Fresh leaves	1/25, f. s.
Arisaema triphyllum (L.) Schott.	Jack-in-the-pulpit	a	Fresh entire plant in flower.	f. s., 1/25 1/35
Do.	do	a–w	Dry root	1/25
Orontium aquaticum L.	Goldenclub	a–w	Fresh entire plant	1/30, f. s.
Peltandra virginica (L.) Kunth.	Virginia arrow-arum	a	do	1/30
Spathyema foetida (L.) Raf.	Skunkcabbage	a	Fresh leaves and root	1/35
Do.	do	a–w	Dry leaves and root	1/50

TABLE 4.—*Botanical classification of plants extracted, together with solvent, part used, and rate of application*—Continued

Family and scientific name	Common name	Solvent	Part used	Dilution
Araliaceae:				
Aralia hispida Vent	Bristly aralia	a-w	Dry root	1/25
Aralia racemosa L.	American spikenard	a-w	do	1/25
Aristolochiaceae:				
Aristolochia serpentaria L.	Virginia snakeroot	a-w	do	1/25
Asarum canadense L.	Canada wildginger	a-w	Dry rhizome and root	1/25
Asclepiadaceae:				
Asclepias pulchra Ehrh.	Hairy milkweed	a	Fresh leaves	1/25
Asclepias syriaca L.	Common milkweed	a	Fresh entire plant in flower.	1/25
Asteraceae:				
Achillea millefolium L.	Common yarrow	a-w	Dry plant	1/25
Do	do	a	Fresh entire plant in flower.	1/25
Do	do	a-w	do	1/25
Ageratum sp.	Ageratum	a	do	1/25
Ambrosia elatior L.	Ragweed (hogweed, bitter-weed).	a	do	1/25
Anacyclus pyrethrum (L.) D. C.	Pellitory	a-w	Dry root	1/25
Antennaria spp.	Pussytoes	a	Fresh entire plant in flower.	1/25
Anthemis arvensis L.	Corn camomile	a	do	1/25
Anthemis nobilis L.	Common camomile	a-w	Dry flowers	1/25
Arctium minus Bernh.	Common burdock	a	Fresh leaves and burs	1/30
Arnica alpina (L.) Olin and Ladau.	Arnica	a-w	Dry leaves	1/25, f. s.
Arnica montana L.	Mountain arnica	a-w	N. F. extract	1/64
Artemisia absinthium L.	Common wormwood	a-w	Dry leaves and flowers	1/25
Artemisia dracunculoides Pursh.	Tarragon	a-w	Dry	1/25
Artemisia vulgaris L.	Mugwort	a-w	Dry whole plant	1/25
Aster novae-angliae L.	New England aster	a	Fresh leaves and flowers	1/25, f. s.
Aster paniculatus Lam.		a-w	do	1/25, f. s.
Chrysanthemum cinerariaefolium Vis.	Pyrethrum	a	Dry flowers and stems	1/100
Chrysanthemum leucanthemum L.	Oxeye daisy	a	Fresh entire plant in flower.	1/25, f. s.
Chrysanthemum parthenium (L.) Bernh.	Feverfew	a-w	Dry entire plant	1/25
Chrysanthemum spp. (cult.).	Chrysanthemum	a	Fresh leaves	1/25
Chrysopsis mariana (L.) Nutt.	Maryland golden-aster.	a	Fresh leaves and flowers	1/25
Cichorium intybus L.	Chicory	a	do	1/35
Cnicus benedictus L.	Blessed thistle	a-w	Dry leaves	1/25
Coreopsis grandiflora Hogg.	Big coreopsis	a-w	Fresh entire plant in flower.	1/30
Echinacea pallida (Nutt.) Britton.	Hedgehog-coneflower	a-w	Dry rhizome and root	1/25, f. s.
Erechtites hieracifolia (L.) Raf.	Fireweed	a-w	Dry entire plant	1/25, f. s.
Erigeron annuus (L.) Pers.	Daisy fleabane	a	Fresh entire plant in flower.	1/50
Erigeron canadensis L.	Horseweed	a	Fresh leaves and heads	1/25, f. s.
Erigeron pulchellus Michx.	Poor-robins-plantain	a	Fresh entire plant in flower.	1/80, f. s.
Eupatorium coelestinum L.	Mistflower	a	do	1/50
Eupatorium hyssopifolium L.	Thoroughwort	a	Fresh leaves and flowers	1/40
Eupatorium perfoliatum L.	Boneset	a	Fresh leaves	1/50
Do	do		N. F. extract	1/64
Eupatorium pubescens Muhl.	Eupatorium	a	Fresh leaves and tops	1/50
Eupatorium purpureum maculatum (L.) Darl.	Joe-pye-weed	a	Fresh leaves and buds	1/50
Galinsoga parviflora Cav.		a	Fresh entire plant in flower.	1/25
Gnaphalium obtusifolium L.	Common everlasting	a	Fresh entire plant	1/25
Grindelia camporum Greene.	Grindelia		N. F. extract	1/64
Helianthus annuus L.	Common sunflower	a-w	Fresh leaves and flowers	1/40, f. s.
Heliopsis helianthoides (L.)	Sunflower heliopsis	a-w	Fresh entire plant in flower	1/25
Hieracium pratense Tausch.	Hawkweed	a	do	1/30
Inula helenium L.	Elecampane	a-w	Dry root	1/25
Krigia biflora (Walt.) Blake.	Cynthia	a	Fresh entire plant in flower.	1/30, f. s.
Lacinaria spicata (L.) Kuntze.	Spike gayfeather	a-w	Dry plant	1/25
Lactuca canadensis L.	Wild lettuce	a	Fresh leaves	1/50

TABLE 4.—*Botanical classification of plants extracted, together with solvent, part used, and rate of application*—Continued

Family and scientific name	Common name	Solvent	Part used	Dilution
Asteraceae—Continued.				
Leontodon taraxacum L.	Dandelion	a	Fresh entire plant in flower.	1/30
Do	do	a	Fresh flowers and stems	1/35, f. s.
Do	do	a–w	Fresh flowers	1/30, f. s.
Do	do	a–w–c	do	1/25
Do	do	a–w [1]	do	f. s.
Matricaria chamomilla L.	False-camomile	a–w	Dry flowers	1/25
Rudbeckia hirta L.	Black eyed-susan	a	Fresh entire plant in flower	1/30
Senecio aureus L.	Golden groundsel		N. F. extract	1/64
Senecio vulgaris L.	Common groundsel		Dry entire plant	1/64
Sericocarpus asteroides (L.) B. S. P.	White-topped aster	a–w	Fresh entire plant in flower.	f. s., 1/25
Silphium laciniatum L.	Compassplant	a–w	Dry entire plant	1/25
Solidago juncea Ait.	Early goldenrod	a	Fresh leaves and flowers	1/25
Solidago sp.	Goldenrod	a–w	Fresh leaves	f. s., 1/25
Sonchus oleraceus L.	Sowthistle	a–w	Fresh leaves and tops	f. s.
Tagetes spp.	Marigold	a	Fresh leaves	1/25
Tanacetum vulgare L.	Common tansy	a–w	Fresh entire plant in flower.	f. s.
Vernonia noveboracensis (L.) Willd.	Common ironweed	a	Fresh leaves and heads	1/35
Balsaminaceae.				
Impatiens balsamina L.	Garden balsam	a–w	Fresh flowers	f. s.
Do	do	a	do	f. s.
Do	do	a–w	Fresh entire plant in flower.	1/30
Impatiens biflora Walt.	Spotted snapweed	a	Fresh leaves and stems	1/25
Berberidaceae:				
Berberis aquifolium Pursh.	Oregon hollygrape		N. F. extract	1/64
Berberis vulgaris L.	European barberry	a–w	Dry root	1/25
Berberis spp.	Barberry	a–w	Dry leaves	1/25
Caulophyllum thalictroides (L.) Michx.	Blue cohosh		N. F. extract	1/64
Do	do	a	Dry root	1/25
Jeffersonia diphylla (L.) Pers.	Twinleaf	a–w	do	1/25
Podophyllum peltatum L.	Common mayapple	a	Fresh entire plant in flower.	1/30
Do	do	a–w	Dry root	1/25
Betulaceae:				
Ostrya virginiana (Mill.) Koch.	American hophornbeam.	a	Dry wood	1/30
Bignoniaceae:				
Bignonia radicans L.	Trumpetcreeper	a	Fresh leaves and flowers	1/25
Catalpa bignonioides Walt.	Southern catalpa	a	Fresh leaves	1/25
Boraginaceae:				
Borago officinalis L.	Common borage	a–w	Dry flowers	1/25
Cynoglossum officinale L.	Common houndstongue.	a–w	Dry root	1/25
Pulmonaria officinalis L.	Common lungwort	a	Dry whole plant	1/25
Do	do	a–w	do	1/25
Symphytum officinale L.	Common comfrey		Dry root	1/35
Brassicaceae:				
Arabidopsis thaliana (L.) Britton.	Mouse-ear cress	a	Fresh entire plant in flower	1/25
Brassica oleracea capitata L.	Cabbage, cultivated	a–w	Fresh leaves	1/25
Brassica nigra (L.) Koch.	Black mustard	a–w	Fresh entire plant in flower	f. s., 1/30
Bursa bursa-pastoris (L.) Britton.	Shepherd's-purse	a–w	Dry entire plant	1/25
Do	do	a–w	Fresh entire plant	1/25
Campe barbarea (L.) W. F. Wight.	Bitter wintercress	a	Fresh entire plant in flower	f. s., 1/30
Erysimum perofskianum Fisch. and Mey.	Afghan blistercress	a–w	do	f. s.
Lepidium virginicum L.	Peppergrass	a	Fresh entire plant	f. s., 1/35
Radicula armoracia (L.) Robinson.	Horseradish	a–w	Dry root	1/25
Buxaceae: Buxus sempervirens L.	Common box	a	Fresh leaves	1/50
Cactaceae: Opuntia vulgaris Mill.	Pricklypear	a–w	Fresh entire plant in flower.	1/30
Campanulaceae: Specularia perfoliata (L.) A. DC.	Venus lookingglass	a	do	1/25
Canellaceae: Canella winterana (L.) Gaertn.	Canella	a–w	Dry bark	1/25
Caprifoliaceae:				
Lonicera japonica Thunb.	Japanese honeysuckle	a	Fresh leaves	1/35
Viburnum dentatum L.	Arrowwood	a–w	do	1/40

[1] Distilled.

TABLE 4.—*Botanical classification of plants extracted, together with solvent, part used, and rate of application*—Continued

Family and scientific name	Common name	Solvent	Part used	Dilution
Caryophyllaceae:				
Alsine media L.	Common chickweed	a	Fresh entire plant in flower.	1/25
Saponaria officinalis L.	Bouncing-bet	a	do	1/35
Silene antirrhina L.	Sleepy catchfly	a	do	1/30
Celastraceae: Celastrus scandens L.	American bittersweet	a	Fresh leaves	1/100
Chenopodiaceae:				
Chenopodium album L.	Lamb's-quarters	a	Fresh entire plant	1/20
Chenopodium ambrosioides L.		a	Fresh leaves	1/30
Chenopodium ambrosioides anthelminticum (L.) A. Gray.	Wormseed	a-w	Fresh stems and fruit	1/30
Cistaceae: Helianthemum canadense (L.) Michx.	Sunrose	a-w	Dry plant	1/25
Combretaceae: Terminalia catappa L.	India-almond		Commercial extract	1/25
Convolvulaceae:				
Exogonium jalapa (L.) Hayne.	Jalap		N. F. extract	1/64
Ipomoea pandurata (L.) Meyer.		a	Fresh leaves and flowers	1/25
Cornaceae:				
Cornus florida L.	Flowering dogwood	a	Fresh leaves	1/35
Nyssa sylvatica Marsh.	Tupelo	a-w	do	1/25
Cucurbitaceae: Citrullus colocynthis Schrad.	Colocynth		U. S. P. extract	1/100
Dipsacaceae: Scabiosa atropurpurea L.	Sweet scabiosa	a-w	Fresh entire plant in flower.	1/25
Droseraceae: Drosera rotundifolia L.	Roundleaf sundew	a	Dry entire plant	1/25
Ebenaceae: Diospyros virginiana L.	Common persimmon		Fresh leaves	f. s., 1/25
Equisetaceae:				
Equisetum hyemale L.	Scouring-rush	a	Dry whole plant	1/30
Equisetum arvense L.	Common horsetail	a	Fresh entire plant	f. s., 1/30
Ericaceae:				
Arctostaphylos uva-ursi (L.) Spreng.	Bearberry		U. S. P. extract	1/64
Do	do	a-w	Dry leaves	1/25
Azalea nudiflora L.	Pinxterbloom	a	Fresh leaves and flowers	f. s.
Chimaphila umbellata (L.) Barton.	Common pipsissewa	a-w	Dry entire plant	1/25
Do	do		N. F. extract	1/64
Epigaea repens L.	Trailing-arbutus	a-w	Dry entire plant	1/25
Gaultheria procumbens L.	Wintergreen	a-w	Fresh leaves	1/25
Kalmia latifolia L.	Mountain-laurel, kalmia.	a	Dry leaves	1/25
Do	do	a	Fresh leaves	1/30
Kalmia angustifolia L.	Lambkill	a-w	do	f. s.
Do	do	a	do	1/40
Oxydendrum arboreum (L.) D. C.	Sourwood	a-w	Dry leaves	1/25
Vaccinium sp.	Blueberry	a-w	Fresh leaves and berries	f. s.
Euphorbiaceae:				
Euphorbia hirsuta (Torr.) Wiegand.	Spurge	a-w	Dry entire plant	1/25
Do	do		N. F. extract	1/64
Euphorbia ipecacuanhae L.	Ipecac spurge	a	Fresh entire plant in flower.	1/30
Mallotus philippinensis (Lamarck) Muell-Arg.	Kamala	a-p	Dry berries	1/25
Ricinus communis L.	Common castor-bean	a-w	Fresh leaves	f. s., 1/25
Do	do	a	do	f. s.
Stillingia sylvatica L.	Stillingia	a-w	Dry root	f. s., 1/25
Fabaceae:				
Acacia longifolia Willd.	Sydney wattle		Commercial extract	1/25
Acacia catechu Willd.	Cutch		do	1/25
Baptisia tinctoria (L.) R. Br.	Yellow wild-indigo	a	Fresh leaves and stems	1/50
Do	do	a	Dry root	1/50
Caesalpinia coriaria Willd.	Divi-divi		Commercial extract	1/25
Cassia chamaecrista L.	Partridge-pea	a	Fresh leaves and flowers	1/40
Cassia marilandica L.	Wild senna	a	Fresh entire plant in flower.	f. s., 1/25
Cracca virginiana L.	Goatsrue	a-w	Dry whole plant in flower	1/25
Cytisus scoparius (L.) Link.	Scotch broom	a-w	Dry tops	1/25
Do	do		N. F. extract	1/64
Deguelia malaccensis (Benth.) Blake.	Derris	b	Dry root	1/25, 1/35
Do	do	a	do	1/25, 1/100
Do	do	a-w	do	1/50

TABLE 4.—*Botanical classification of plants extracted, together with solvent, part used, and rate of application* —Continued

Family and scientific name	Common name	Solvent	Part used	Dilution
Fabaceae—Continued.				
Galega officinalis L.	Common goatsrue	a–w	Dry whole plant in flower	1/25
Genista tinctoria L.	Woadwaxen	a–w	Dry flowers and seeds	1/25
Glycyrrhiza glabra L.	Common licorice	a–w	Dry root	1/25
Gymnocladus dioica (L.) Koch.	Kentucky coffeetree	a	Fresh leaves	1/35
Haematoxylon campechianum L.	Logwood (hematin)		Two commercial extracts	1/25
Ichthyomethia piscipula (L.) Hitchc.	Jamaica fish-poison	a	Dry bark	1/35
Do	do	a–b–g	do	1/25
Do	do	a–g	do	1/35
Lupinus perennis L.	Sun-dial lupine	a	Fresh entire plant in flower.	1/30
Melilotus alba Desv.	White sweet clover	a	do	1/25
Melilotus officinalis (L.) Lam.	Yellow sweet clover	a	do	1/25
Physostigma venenosum Balf.	Calabar-bean	a–w	Dry seeds	1/25
Psoralea pedunculata (Mill.) Vail.	Sampson-snakeroot	a–w	Dry root	1/25
Robinia pseudacacia L.	Common locust	a	Fresh leaves	1/35
Stylosanthes biflora (L.) B. S. P.	Pencil flower	a	Fresh leaves and flowers	1/25
Trifolium agrarium L.	Hop clover	a	Fresh entire plant in flower.	1/25
Trifolium arvense L.	Rabbit-foot clover	a	do	1/25
Trigonella foenum-graecum L.	Fenugreek	a–w	Dry seed	1/25
Vicia villosa Roth	Hairy vetch	a	Fresh entire plant in flower.	1/25
Fagaceae:				
Castanea dentata (Marsh.) Borkh.	American chestnut		Commercial extract	1/25
Fagus grandifolia Ehrh.	American beech	a	Fresh leaves	1/25
Quercus borealis maxima (Marsh.) Ashe.	Common red oak	a	do	1/25
Quercus velutina Lam.	Black oak (quercitron)	a	do	1/25
Do	do		Commercial extract	1/25
Quercus spp.	Gallnut		do	1/25
Do	Valonia		do	1/25
Fumariaceae:				
Bikukulla canadensis (Goldie) Millsp.	Squirrelcorn	a–w	Dry tubers	1/25
Fumaria officinalis L.	Common fumitory	a–w	Dry entire plant	1/25
Gentianaceae:				
Gentiana lutea L.	Yellow gentian	a–w	Dry root	1/25
Menyanthes trifoliata L.	Common bogbean	a–w	Dry leaves	1/25
Sabbatia angularis (L.) Pursh.	Rosegentian	a–w	Dry entire plant in flower	1/25
Swertia chirayita (Roxb.) Lyons.	Chiretta	a–w	Dry entire plant	f. s., 1/25
Geraniaceae: Geranium carolinianum L.	Cranesbill geranium	a	Fresh entire plant in flower.	f. s., 1/30
Ginkgoaceae:				
Ginkgo biloba L.	Maidenhair-tree	a	Fresh leaves	1/25, 1/35
Do	do	p	do	1/100
Haemodoraceae: Gyrotheca tinctoria (Walt.) Salisb.	Redroot	a–w	Fresh entire plant in flower.	f. s.
Hamamelidaceae:				
Hamamelis virginiana L.	Common witch-hazel		N. F. extract	5/64
Liquidambar styraciflua L.	Sweetgum	a	Fresh leaves	f. s., 1/25
Hydrophyllaceae: Eriodictyon californicum (Hook. and Arn.) Greene.	Yerba santa	a–w	Dry leaves	1/25
Hypericaceae:				
Hypericum perforatum L.	St. Johnswort	a	Dry entire plant	1/25
Do	do	a	Fresh entire plant in flower.	1/25
Iridaceae:				
Crocus sativus L.	Crocus (saffron, Amer.)	a–w	Dry entire plant	1/25
Iris versicolor L.	Blueflag iris	a	Fresh entire plant in flower.	1/30
Sisyrinchium sp.	Blue-eyed-grass	a	do	1/30
Juglandaceae:				
Hicoria sp.	Hickory	a	Fresh leaves	1/25
Hicoria glabra (Mill.) Britton.	Pignut	a	Fresh leaves	1/25
Juglans cinerea L.	Butternut	a–w–g	Dry bark of root	1/25

TABLE 4.—*Botanical classification of plants extracted, together with solvent, part used, and rate of application*—Continued

Family and scientific name	Common name	Solvent	Part used	Dilution
Juncaceae: Juncus effusus L.	Common rush	a	Fresh entire plant in flower.	1/30
Lauraceae:				
Benzoin aestivale (L.) Nees.	Spicebush	a	Fresh leaves and berries	1/25
Laurus nobilis L.	Grecian laurel	a–w	Dry leaves	1/25
Do	do	a	do	1/25
Liliaceae:				
Allium canadense L.	Meadow garlic	a	Fresh stems and bulbs	f. s., 1/30
Aloe vera L.	True aloe	a–w	Dry leaves	f. s., 1/25
Colchicum autumnale L.	Common autumn-crocus.		U. S. P. extract	1/64
Convallaria majalis L.	Lily-of-the-valley	a–w	Dry leaves	1/25
Erythronium americanum Ker.	Common troutlily	a	Fresh entire plant in flower.	f. s., 1/30
Helonias bullata L.	Swamp-pink	a	do	1/30
Hemerocallis fulva L.	Tawny daylily	a	do	f. s., 1/30
Hyacinthus orientalis L.	Common hyacinth (cult.).	a	Fresh flowers and stems	1/25
Lilium superbum L.	American Turkscap lily.	a	Fresh leaves and pods	1/35
Medeola virginiana L.	Cucumber-root	a	Fresh leaves and stems	1/25
Ornithogalum umbellatum L.	Common star-of-Bethlehem.	a	Fresh entire plant in flower.	1/30
Polygonatum biflorum (Walt.) Ell.	Small Solomonseal	a–w	Dry entire plant	1/25
Polygonatum commutatum Dietr.	Great Solomonseal	a	Fresh entire plant in flower.	1/25
Schoenocaulon officinale Schecht.	Sabadilla	a–ac	Dry seed	1/25
Smilax rotundifolia L.	Common greenbrier	a	Fresh leaves	1/25
Trillium erectum L.	Purple trillium	a–w	Dry rhizome and root	1/25
Tulipa gesneriana L.	Common tulip	a	Fresh entire plant in flower.	1/30
Unifolium canadense (Desf.) Greene.		a	do	1/30
Urginea maritima (L.) Baker.	Sea-onion	a–w	Dry bulb	1/50
Do	do		U. S. P. extract	1/64
Uvularia perfoliata L.	Wood merrybells	a	Fresh entire plant in flower.	f. s., 1/35
Vagnera trifolia (L.) Morong.	False Solomonseal	a	do	1/25, 1/35
Veratrum viride Ait.	American false-hellebore.	a–w	Dry root	1/25
Do	do		U. S. P. extract	1/64
Do	do	a	Fresh leaves and stems	1/30
Veratrum album L.	False-hellebore	a–w	Dry root	1/25
Lobeliaceae:				
Lobelia inflata L.	Indian-tobacco	a–w	Dry leaves and tops	1/25
Do	do		N. F. extract	1/64
Lobelia cardinalis L.	Cardinalflower	a–w	Fresh entire plant in flower.	f. s., 1/25
Loganiaceae:				
Strychnos ignatii Bergius	Ignatia	a–w	Dry beans	1/25
Strychnos nux-vomica L.	Nux vomica		N. F. extract	1/64
Loranthaceae: Phoradendron flavescens (Pursh.) Nutt.	American mistletoe	a–w	Dry entire	1/25
Lythraceae: Lythrum salicaria L.	Purple loosestrife	a–w	Fresh entire plant in flower.	1/25
Magnoliaceae:				
Liriodendron tulipifera L.	Tuliptree	a	Fresh leaves	1/25
Magnolia virginiana L.	Sweetbay	a	do	f. s.
Malvaceae: Hibiscus trionum L.	Flower-of-an-hour	a	Fresh entire plant in flour.	1/25
Meliaceae: Guarea rusbyi (Britton) Rusby.	Cocillana	a–w	Dry bark	f. s., 1/25
Menispermaceae:				
Anamirta cocculus (L.) Wight and Arn.	Fish-berries	a–w	Dry fruit	1/25
Do	do		N. F. extract	1/64
Menthaceae:				
Collinsonia canadensis L.	Citronella horsebalm	a–w	Dry entire plant	1/25
Cunila origanoides (L.) Britton.	Stonemint	a–w	do	1/25
Hedeoma pulegioides (L.) Pers.	Pennyroyal	a–w	Dry leaves	1/25
Hyssopus officinalis L.	Hyssop	a–w	do	1/25
Koellia flexuosa (Walt.) MacM.	Slender mountain-mint.	a	Fresh leaves and stems	1/25
Lamium amplexicaule L.	Deadnettle	a	Fresh entire plant in flower.	1/30

TABLE 4.—*Botanical classification of plants extracted, together with solvent, part used, and rate of application*—Continued

Family and scientific name	Common name	Solvent	Part used	Dilution
Menthaceae—Continued.				
Leonurus cardiaca L.	Common motherwort	a-w	Dry entire plant	1/25
Lycopus virginicus L.	Bugleweed	a-w	do	1/25
Marrubium vulgare L.	Common hoarhound	a	Fresh leaves and stems	1/25
Do	do	a-w	Dry leaves	1/30
Mentha spicata L.	Spearmint	a-w	Dry leaves and tops	f. s., 1/25
Mentha canadensis L.	American wild mint	a-w	Fresh entire plant in flower.	f. s., 1/2
Mentha arvensis L.	Field mint	a-w	do	1/25
Monarda punctata L.	Spotted beebalm	a	Fresh leaves and flowers	1/25
Monarda sp.	Beebalm	a	Fresh entire plant	1/25
Nepeta cataria L.	Catnip	a	Fresh leaves and stems	f. s., 1/25
Do	do	a-w	Dry leaves	1/25
Do	do		N. F. extract	1/64
Nepeta hederacea (L.) Trevisan.	Ground-ivy	a	do	1/25
Do	do	a	Fresh entire plant in flower.	f. s., 1/35
Origanum majorana L.	Sweet marjoram	a-w	Dry leaves and flowers	1/25
Rosmarinus officinalis L.	Rosemary	a-w	Dry leaves	1/25
Do	do	a-w	Dry flowers	1/25
Salvia splendens Ker.	Scarlet sage	a	Fresh entire plant in flower.	1/30
Salvia triloba L.	Greek sage	a-w	Dry leaves	1/25
Satureia hortensis L.	Summer savory	a-w	do	1/25
Scutellaria lateriflora L.	Mad-dog skullcap	a-w	Dry entire plant	1/25
Do	do		N. F. extract	1/64
Do	do	a	Fresh entire plant in flower.	1/25
Stachys officinalis (L.) Franch.	Common betony	a-w	Dry entire plant	1/25
Teucrium canadense L.	American germander	a-w	Fresh entire plant in flower.	f. s., 1/25
Thymus vulgaris L.	Common thyme	a-w	Dry leaves	1/25
Do	do		N. F. extract	1/64
Monimiaceae: Peumus boldus Mol.	Boldo	a	Dry leaves	1/25
Moraceae: Chlorophora tinctoria (L.) Gaud.	Fustic		Commercial extract	1/25
Myricaceae:				
Comptonia peregrina (L.) Coult.	Sweetfern	a	Fresh leaves	1/50
Myrica cerifera L.	Southern waxmyrtle	a-w	Dry bark of root	1/30
Myrica carolinensis Mill.	Northern bayberry	a	Fresh leaves and berries	1/30
Myrtaceae:				
Eucalyptus globulus Labill.	Blue gum	a-w	Dry leaves	1/25
Do	do		U. S. P. extract	1/64
Syzagium cumini (L.) Skeels.	Jambolan-plum	a-w	Dry bark and seeds	1/25
Nymphaeaceae: Nymphaea advena Ait.	Spatterdock	a	Fresh leaves and stems.	1/30
Oleaceae:				
Chionanthus virginica L.	White fringe tree	a-w	Dry bark of root	1/25
Fraxinus americana L.	White ash	a	Fresh leaves	1/25
Ligustrum vulgare L.	European privet	a	do	1/25
Syringa vulgaris L.	Common lilac	a	Fresh leaves and flowers	f. s., 1/30
Orchidaceae: Habenaria blephariglottis (Willd.) Torr.	White fringe-orchid	a-w	Fresh entire plant in flower.	f. s.
Osmundaceae: Osmunda cinnamomea L.	Cinnamon fern	a	Fresh young fronds	1/30
Oxalidaceae: Oxalis stricta L.	Common yellow oxalis	a	Fresh entire plant in flower.	f. s., 1/35
Papaveraceae:				
Chelidonium majus L.	Celandine	a-w	Dry entire plant	1/25
Do	do	a	Fresh entire plant in flower.	1/30
Passifloraceae: Passiflora incarnata L.	Maypop	a-w	Dry entire plant	1/25
Phoenicaceae:				
Areca catechu L.	Betel palm	a-w	Dry nuts	1/50
Serenoa serrulata (Michx.) Hooker.	Saw palmetto	a-w	Dry berries	1/25
Phytolaccaceae:				
Phytolacca americana L.	Common pokeberry	a-w	do	1/50
Do	do	a-w	Dry root	1/30
Do	do	a	Fresh leaves and stems	1/50
Pinaceae:				
Abies concolor (Gord.) Murray.	White fir	p	Fresh leaves and twigs	1/50
Do	do	a	do	1/50, 1/100
Abies veitchii Lindl.	Veitch fir	a	Fresh leaves	1/35
Chamaecyparis thyoides (L.) B. S. P.	Whitecedar	a-w	do	1/25

TABLE 4.—*Botanical classification of plants extracted, together with solvent, part used, and rate of application*—Continued

Family and scientific name	Common name	Solvent	Part used	Dilution
Pinaceae—Continued.				
Juniperus sabina L.	Savin	a	Dry tops	1/50
Juniperus virginiana L.	Redcedar	a	Fresh lower leaves	1/25
Juniperus communis L.	Common juniper	a-w	Dry berries	1/25
Picea orientalis (L.) Carr.	Oriental spruce	a	Fresh leaves and twigs	1/50
Pinus spp.	Pine		Commercial	1/50
Pinus virginiana Mill.	Scrub pine	a	Fresh needles and young twigs.	1/25
Pinus rigida Mill.	Pitch pine	a-w	Fresh needles	1/25
Thuja occidentalis L.	American arborvitae	a	Fresh leaves and twigs	1/35
Tsuga canadensis (L.) Carr.	Canada hemlock	a-w	do	1/25
Do.	do		Commercial extract	1/25
Piperaceae:				
Piper angustifolium Ruiz and Pavon.	Matico	a-w	Dry leaves	1/25
Saururus cernuus L.	Common lizardtail	a-w	Fresh entire plant	1/25
Plantaginaceae:				
Plantago major L.	Common plantain	a	Dry leaves	1/25
Do.	do	a	Fresh entire plant	f. s
Plantago lanceolata L.	Buckhorn plantain	a-w	do	f. s
Poaceae:				
Agropyron repens (L.) Beauv.	Quackgrass	a	Dry rhizome and root	1/50
Holcus lanatus L.	Velvet grass	a	Fresh entire plant in flower.	1/30
Polemoniaceae:				
Phlox subulata L.	Moss phlox	a	do	f.s., 1/25
Phlox paniculata L.	Garden phlox	a	Fresh plant in flower	1/30
Polygalaceae: Polygala senega L.	Seneca-snakeroot		N. F. extract	1/64
Polygonaceae:				
Fagopyrum vulgare Hill.	Common buckwheat	a	Fresh entire plant	f.s., 1/25
Rumex acetosa L.	Garden sorrel	a	do	1/25
Polypodiaceae:				
Adiantum capillus-veneris L.	Southern maidenhair	a-w	Dry entire plant	1/25
Phyllitis scolopendrium (L.) Newman.	Hartstongue	a-w	Dry fronds	1/25
Pteridium aquilinum (L.) Kuhn.	Bracken	a-w	Fresh fronds	1/25
Polyporaceae: Polyporus officinalis Fries.	Agaric	a-w	Dry fruit	1/25
Polytrichaceae: Polytrichum juniperinum Willd.	Haircap moss	a-w	Dry entire plant	1/25
Pontederiaceae: Pontederia cordata L.	Pickerelweed	a	Fresh entire plant	1/25
Portulacaceae: Claytonia virginica L.	Virginia springbeauty	a	Fresh entire plant in flower.	1/25
Plumbaginaceae: Limonium carolinianum (Walt.) Britton.	Sea-lavender	a-w	do	1/25
Primulaceae: Lysimachia terrestris (L.) B. S. P.	Swampcandle	a	do	1/30
Ranunculaceae:				
Aconitum napellus L.	Aconite	a-w	Dry root	1/25
Adonis vernalis L.	Spring adonis	a-w	Dry entire plant	1/25
Anemone pulsatilla L.	European pasqueflower.	a-w	do	1/25
Anemone quinquefolia L.	American wood anemone.	a	Fresh entire plant in flower.	f.s.
Caltha palustris L.	Marshmarigold	a	do	f.s., 1/35
Cimicifuga racemosa (L.) Nutt.	Cohosh bugbane		U. S. P. extract	1/64
Do.	do		Dry root	1/25
Delphinium staphisagria L.	Larkspur	a-w	Dry seed	1/50
Helleborus niger L.	Christmas-rose	a-w	Dry rhizome	1/25
Helleborus foetidus L.	Hellebore	a-w	Dry rhizome and root	1/25
Hepatica triloba Chaix.	Roundlobe hepatica	a-w	Dry leaves	1/25
Hydrastis canadensis L.	Goldenseal		U. S. P. extract	1/64
Nigella sativa L.	Fennel flower	a-w-c	Dry seed (2 extracts)	1/25, f. s.
Do.	do	a-w-c	do	1/25, f. s.
Ranunculus septentrionalis Poir.	Swamp buttercup	a	Fresh entire plant in flower.	1/30
Thalictrum polygamum Muhl.	Tall meadowrue	a	Fresh leaves and flowers	1/50
Resedaceae: Reseda odorata L.	Common mignonette	a	Fresh entire plant in flower.	f.s.
Rhamnaceae:				
Ceanothus americanus L.	Jersey-tea	a	Fresh leaves and flowers	1/30
Rhamnus cathartica L.	Common buckthorn	a	Dry berries	1/50

TABLE 4.—*Botanical classification of plants extracted, together with solvent, part used, and rate of application* —Continued

Family and scientific name	Common name	Solvent	Part used	Dilution
Rosaceae:				
Hagenia abyssinica Gmel.	Kousso	a	Dry flowers	1/25
Potentilla argentea L.	Silver cinquefoil	a	Fresh entire plant in flower.	1/30
Pyrus communis L.	Common pear (Kieffer).	a	Fresh leaves	1/25
Pyrus sp.	Common pear	a–w	do	1/25
Quillaja saponaria Mol.	Soapbark		N. F. extract	1/64
Rubiaceae:				
Cephalanthus occidentalis L.	Common buttonbush	a	Fresh leaves and flowers	1/35
Cinchona succirubra Pavon	Cinchona	a–w–g	Dry bark	1/25
Galium aparine L.	Bedstraw	a–w	Dry entire plant	1/25
Galium triflorum Michx.	Fragrant bedstraw	a	Fresh leaves and stems	1/50
Mitchella repens L.	Partridgeberry	a–w	Dry entire plant	1/25
Ourouparia gambia (Hunter) Baillon.	Gambier		Commercial extract	1/25
Rutaceae:				
Barosma betulina (Thunb.) Bartl. and Wendl.	Buchu		U. S. P. extract	1/25
Pilocarpus jaborandi Holmes.	Pilocarpus		N. F. extract	1/64
Do	do	a–w	Dry leaves	1/25
Ruta graveolens L.	Common rue	a–w	Dry entire plant	1/25
Zanthoxylum americanum Mill.	Common prickly-ash	a–w	Dry bark	f. s., 1/25
Salicaceae: Populus nigra L.	Black poplar		Dry buds	1/25
Santalaceae: Comandra umbellata (L.) Nutt.	Comandra	a	Fresh entire plant in flower	1/25
Parietaria pennsylvanica Muhl.	Pellitory	a–w	Dry root	1/25
Saxifragaceae: Hydrangea arborescens L.	Smooth hydrangea	a–w	do	1/25
Scrophulariaceae:				
Antirrhinum spp.	Snapdragon	a	Fresh entire plant in flower.	1/25
Aureolaria pedicularia (L.) Raf.	Gerardia	a	Fresh leaves and flowers	1/30
Chelone glabra L.	White turtlehead	a–w	Dry leaves	1/25
Digitalis purpurea L.	Common foxglove		N. F. extract	1/100
Euphrasia officinalis L.	Eyebright	a–w–ac	Dry entire plant	1/25
Linaria vulgaris Hill.	Common toadflax	a	Fresh entire plant in flower.	f. s., 1/25
Melampyrum lineare Lam.	Cowwheat	a–w	Fresh entire plant	1/25
Scrophularia marylandica L.	Figwort	a–w	Dry leaves	1/25
Verbascum thapsus L.	Common mullein		N. F. extract	1/64
Do	do	a	Fresh leaves and heads	1/40
Veronica officinalis L.	Common speedwell	a–w	Dry entire plant	1/25
Veronica virginica L.	Culvers-physic	a–w	Dry rhizome and root	1/25
Simaroubaceae:				
Ailanthus altissima (Mill.) Swingle.	Ailanthus	a	Fresh leaves	f. s., 1/25
Do	do	a–w	do	f. s., 1/25
Picrasma excelsa (Sw.) Planch.	Quassia	a–w	Dry chips	1/35
Do	do		N. F. extract	1/64
Solanaceae:				
Atropa belladonna L.	Belladonna		U. S. P. extract	1/64
Datura stramonium L.	Jimsonweed		do	1/100
Do	do		Dry leaves	1/25
Hyoscyamus niger L.	Henbane		U. S. P. extract	1/125
Lycopersicon esculentum Mill.	Tomato		Juice from fresh leaves	1/2–1/4
Do	do	a	Fresh leaves	1/25
Do	do	a [1]	do	1/100
Do	do	a–w	do	1/4–1/35
Nicotiana tabacum L.	Common tobacco		Commercial extract	(6 extr.)
Do	do		Juice from leaves	1/2–1/4
Do	do		Leaf wax	f. s.
Do	do	a	Fresh leaves	1/10
Do	do	p	do	1/25
Do	do	an	Fresh leaves	1/25
Do	do	pn	do	1/25
Do	do	a [2]	do	1/10
Petunia hybrida Vilm.	Common petunia	a	Fresh flowers	1/25, f. s.
Do	do	a–w	Fresh plant in flower	1/25, f. s.
Solanum carolinense L.	Horsenettle		N. F. extract	1/64
Do	do	a–w	Dry root	f. s., 1/25
Do	do	a–w	Dry berries	1/25

[1] Distilled.

[2] Recovered.

TABLE 4.—*Botanical classification of plants extracted, together with solvent, part used, and rate of application* —Continued

Family and scientific name	Common name	Solvent	Part used	Dilution
Solanaceae—Continued.				
Solanum dulcamara L.	Bitter nightshade		N. F. extract	1/64
Do	do	a–w	Dry twigs	1/25
Solanum tuberosum L.	Potato		Juice from fresh leaves	1/2–1/4
Do	do	a	Fresh leaves	1/10–1/25
Do	do	p	do	1/50
Do	do	a–w	do	1/50
Sparganiaceae: Sparganium americanum Nutt.	Bur-weed	a	Fresh leaves and burs	1/25
Taxaceae: Taxus cuspidata Sieb. and Zucc.	Japanese yew	a	Fresh leaves and twigs	1/25
Tropaeolaceae:				
Tropaeolum majus L.	Common nasturtium	a	Fresh plant in flower	f. s.
Do	do	a–w	do	1/25
Typhaceae:				
Typha latifolia L.	Common cattail	a	Fresh entire plant	1/25, f. s.
Typha angustifolia L.	Narrowleaf cattail	a	do	1–/25
Urticaceae:				
Cannabis sativa L.	Common hemp		U. S. P. extract	1/64
Humulus lupulus L.	Common hop	a–w	Dry strobile	1/25
Morus sp.	Mulberry	a	Fresh leaves	f. s., 1/25
Toxylon pomiferum Raf.	Osage-orange		Commercial extract	1/25
Verbenaceae:				
Lippia dulcis Trevir.	Lippia	a–w	Dry	1/25
Verbena hastata L.	Blue vervain	a	Fresh leaves and flowers	1/35
Violaceae:				
Viola tricolor L.	Common pansy	a–w	Dry entire plant	1/50
Viola papilionacea Pursh.	Butterfly violet	a	Fresh entire plant in flower	1/30
Zingiberaceae:				
Alpinia officinarum Hance	Galangal	a–w	Dry rhizome	1/25
Curcuma zedoaria Rosc.	Zedoary	a–w	do	1/25

NOTE.—N. F. and U. S. P. extracts (made according to their respective standards) were purchased. The extracts designated as "commercial" are ones which are used in tanning and as dyestuffs, with the exception of those from tobacco.

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EXPERIMENTS IN NAVAL STORES PRACTICE

BY

LENTHALL WYMAN

Associate Silviculturist, Southern Forest Experiment Station
Branch of Research, Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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INTRODUCTION

The two most important trees for turpentining[2] in the United States are the longleaf pine (*Pinus palustris* Mill.) and the slash pine (*P. caribaea* Morelet) which occur in the South Atlantic and Gulf States from Virginia to Texas. In Figure 1, which gives the range of the two trees, the wider distribution of longleaf is evident. Slash pine is confined for the most part to the wetter soils in the Southeast. Both occupy land that is of little or no value as farm land or pasture.

Since early days these trees have been worked for gum from which turpentine and rosin are distilled, but only recently has any system-

[1] Acknowledgment for their substantial contribution to the experiments detailed here is due L. C. Powell, W. H. Smith, and Merion Johns, of Starke, Fla., through whose cooperation was furnished the timber on which the tests were conducted. Assistance was also given by the Pine Institute of America in lending weather instruments, by a tool company in furnishing many of the tools used, and by the Bureau of Chemistry and Soils in supplying analyses of gum. The advice of Eloise Gerry and Austin Cary, of the Forest Service, has been particularly helpful. Carl F. Speh, of the Pine Institute, has also offered many valuable suggestions.

[2] For the definiteness of naval-stores and forestry terminology see Glossary, p. 54.

atic attempt been made to moderate this turpentining work for the benefit of future turpentine and timber values. A decade ago hacks with a large cutting edge were in general use. These were mostly Nos. 1½ and 2, in contrast with the No. 1 hack most widely used to-day and the No. 0 now coming into use. No. 2 hacks chipped streaks an inch deep and took off an inch of wood in height at every chipping. In four years faces were 12 feet high.

The deep chipping of earlier years has given way to somewhat more conservative work, but in the meantime a great deal of damage has been done through the mechanical weakening of the timber. In many heavily worked stands of young timber one tree out of every four has been broken by hurricane winds. (Fig. 2.) Hurricane

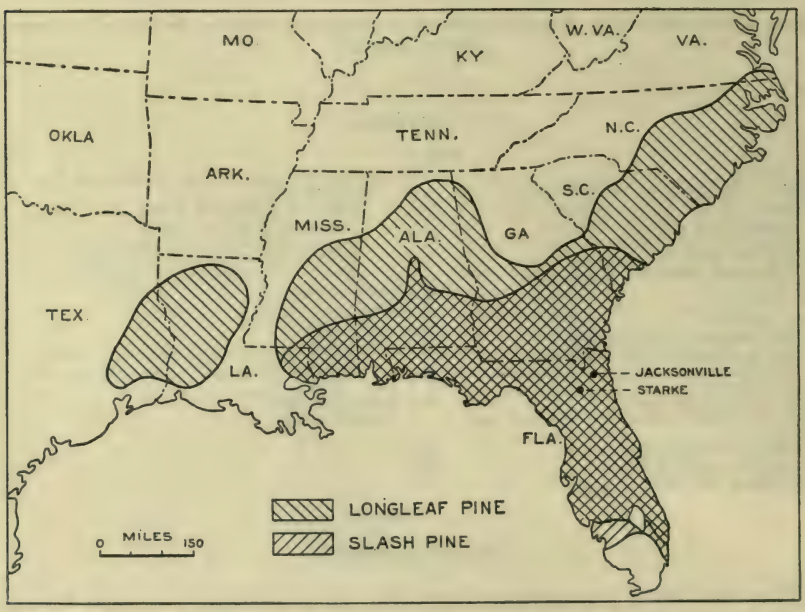

FIGURE 1.—Natural range of slash pine and longleaf pine in the Southern States

damage is ordinarily restricted to small areas, but the 1928 hurricane blew down about 1 per cent of the turpentined trees in several counties in northern Florida and southern Georgia. Vining (*40*)[3] reports a great deal of wind shake in turpentined trees following this storm. Deep chipping, aside from the mechanical damage for which it is responsible, causes a great deal of dry facing, especially in slash pine timber, and this, in turn, is followed by insect and fungus attacks, which cause further damage and loss. (Fig. 3.)

It is common to find chippers cutting away 40 per cent or more of the bark periphery for a single face, and where two or more faces are being worked concurrently the bark bars between faces are frequently cut away. Such heavy work impairs the vitality of the tree and lowers gum yields. Even where some care in chipping has

[3] Italic numbers in parenthesis refer to Literature Cited, page 57.

been exercised bark bars are often so reduced in width as to result in injury to the tree and a lowering of gum yields.

The growing local scarcity of suitable turpentine timber, combined with the keen competition for timber, has brought about the

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FIGURE 2.—Destructive methods of chipping cause heavy losses from windbreak annually

chipping of trees even as small as 6 inches in diameter, usually at a loss to the operator because of their very small gum yield. Many of these smaller trees are badly crippled by turpentining and not

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FIGURE 3.—Double facing and deep chipping followed by high water and an attack by Ips bettles have wrecked this stand

only put on no growth but, by remaining on the land in a nearly stagnant condition for years, effectively retard the establishment of new forest growth.

Annual woods burning by naval-stores men is another practice injurious to forest growth. Of course, woods burning is not confined to the turpentine stands; others beside operators are responsible for a very large number of the fires; but practically all turpentine men burn over their woods. They claim that in the past it has been unpractical, if not impossible, to exclude incendiary fires, since such fires are likely to come at a time when there is an accumulation of chips, grass, leaves, and other inflammable material around the trees. Under such conditions, even light surface fires can creep up to the turpentine faces and ignite them. Accordingly, operators rake away all grass, chips, and leaves from the trees which are being tapped, and then burn the woods. Unfortunately, trees on which old faces have been worked out, but which are still potential producers of timber as well as of later gum yields, are not protected, and these faces burn year after year.

These results of uncontrolled turpentining methods suffice to indicate the havoc such methods can bring about in ruining small trees, checking the growth rate of others, and reducing the timber value of many trees that otherwise might yield a return in both gum and lumber. Practically all the longleaf and slash pines destined for ties, poles, or lumber are turpentined before they are cut, and many of them before they reach seed-bearing size.

Thus far the industry has prospered, largely at the cost of its future well-being and with reckless disregard of the need of sustaining future supplies of raw materials. This need, so important to the welfare of the industry, has by no means been disregarded intentionally but rather for lack of any dependable information and convincing facts leading to improved practice. The need has been for systematic investigative work upon which might be based a scientific plan of naval-stores management that would insure a sustained supply of timber for the naval-stores industry and the landowner.

Studies of turpentine practice made prior to 1923 resulted in several great improvements in the industry. Such work as that of Ashe (*1*) and Herty (*18*, *19*) did much to expose the wasteful "boxing" system of 30 years ago, whereby the gum was caught in a deep niche or box cut into the base of the tree below the face. Herty's recommendations were put into practice in overmature longleaf pine in northwestern Florida on the Choctawhatchee (then the Florida) National Forest under the direction of Forest Supervisor I. F. Eldridge and Ranger E. R. McKee (*10*) in 1908. In 1916 some experiments in the use of narrow faces on virgin timber were started by McKee (*26*) on the Florida National Forest.

Before 1920 all experimental work was in virgin timber, but at that time Cary (*6*) started a number of field tests in second-growth stands, in cooperation with timber owners at various points in the South, and these have done much to attract widespread attention to the problems peculiar to second-growth working. In 1923 Cary, Gerry, and McKee (*15*) established a set of experimental plots in mature timber on the Florida National Forest, from which results were obtained that threw new light on the relation of height of streak to wood structure and gum yield.

In 1921, coincident with the establishment of the Southern Forest Experiment Station, the Forest Service began the systematic study of naval-stores practices, and in 1923 started a series of tests at a branch station at Starke, in Bradford County, Fla. This location, although perhaps a little south of the center of the region, was deemed to be representative of the second-growth turpentine timber belt. These investigations were designed to determine the best practice that would combine profitable turpentining with sustained gum yields and the conservation of southern pine forests.

Among the more important problems on which studies were begun in 1923 are the effect on naval-stores management of varying the height of chip removed with each streak, the effect on gum and timber yields of cutting deep or shallow streaks, and the effect on yields and the life of the turpentining operation of width of face and back facing. Another series of tests had to do with the effect on gum yield of stand density, tree diameter, crown size, and growth rate.

In these studies it was apparent that the species chipped must be taken into account with nearly every other factor considered. Although longleaf pine sometimes grows in mixture with slash pine, normally the two species occur in somewhat different situations. As already stated, slash pine commonly occurs on wetter land than longleaf. It might well be assumed, also, that the two species respond differently to chipping. Observation indicated that slash was more susceptible to injury than longleaf pine. Because of these differences in behavior, it was planned to duplicate as many as possible of the chipping tests in slash and longleaf.

LOCATION AND DESCRIPTION OF STARKE TESTS

No Government-owned timber suitable for naval-stores studies in second-growth stands was available in 1923, and it was therefore necessary to obtain the cooperation of private interests which would allow the Forest Service to use their timber for this purpose. From R. A. and W. H. Smith, of Hawthorne, Fla., was obtained the use of 25 acres of slash pine for experimental work (Sampson tract) and from the Smith-Powell Naval Stores Co., of Starke, Fla., the needed longleaf pine (Powell tract).

SLASH PINE AREA (SAMPSON TRACT)

The slash pine experimental area is located 7 miles southwest of Starke on the north shore of Sampson Lake, a shallow lake about 2 miles wide. The timber tract extends back from the normal shore line for a distance of 800 feet, but 90 per cent of the trees used in these first experiments occur in a band 250 feet wide close to the lake shore. The timber is fairly representative of slash pine in the flatwoods region and from the standpoint of naval-stores production may be considered about average.

The shore line of the lake is normally 200 feet from the edge of the timber, and the water level is 12 to 15 inches lower than the ground level where the timber stand commences, but a rise of 4 or 4½ feet in the lake level (such as occurs almost every year) floods the timber in a strip 200 to 250 feet wide. Such floods occurred in April, June,

July, or September in 3 out of the 5 years of this record and lasted from 3 to 10 weeks. There is not more than 6 feet difference in elevation between the highest and lowest parts of this whole area. It is evident that the water table is close to the surface and that the trees seldom suffer from drought. The absolute elevation is 150 feet above sea level. The rainfall is very irregular. Almost any month from March to October may have 8 inches of rain or enough to cause a sharp rise in the water level of the lake.

The Sampson tract supports practically a pure stand of slash pine, with occasional pond cypresses (*Taxodium ascendens* Brongniart) that have been badly damaged by suppression and fires. The dominant slash pine trees were 33 to 35 years old in 1923 and averaged 82 feet tall and 11 inches d. b. h.[4] They had grown rapidly up to the age of 28 or 30 years, but at about that time a marked slowing down in the growth rate occurred because of overcrowding. In basal area, or total area of the cross sections of all trees at breast height, individual tenth acres varied at the rate of between 140 and 220 square feet per acre. The average basal area per acre was 150 square feet, as opposed to 160 square feet in normally stocked timber stands of this age and site (*39*). The number of faces per acre which it would have been possible to cut, allowing one face on trees over 8.5 inches and two faces on trees over 12 inches d. b. h., ranged from 110 to 250, with an average of 154 per acre on the 3.5 acres to which the tests were confined. The site index was found to be 95 feet (at 50 years) or considerably better than the average for the South. The trees were healthy, only a very few having visible fire scars. Fires had been infrequent and light near the lake, owing to the wetness of the soil and humus, but, even so, had been effective in removing the cypress from the stand. As a result of relative freedom from fires, the leaf litter and humus had accumulated until they were about 3 inches deep.

Because of the density of the pine stand, there is practically no underbrush or pine reproduction and only a very sparse grass cover. Where the stand is open, gall berry (*Ilex glabra* (L) A. Gray), ground laurel (*Kalmia hirsuta* Walter), huckleberry (*Gaylussacia dumosa* A. Gray), and blueberry (*Vaccinium myrsinites* Lambert) are characteristic species forming the ground cover. Several species of wire grass are common, the most typical being *Aristida spiciformis* Elliot. St. Johnswort (*Hypericum fasciculatum* Lambert) is very common along the lake shore outside the timber belt.

The soil is classified as Norfolk fine sand and is composed of 8 inches of light-gray to dark-gray fine sand surface soil underlain by a yellow subsoil. In depressions from 2 to 4 inches of muck may occur. The subsoil, when saturated, is of a quicksand type, and is wet at practically all seasons of the year, a situation favorable to the development of slash pine. The surface soil is moderately well drained.

LONGLEAF PINE AREA (POWELL TRACT)

The longleaf tract used for these turpentining tests is located about 3½ miles southeast of Starke and approximately 8 miles east of the Sampson Lake slash pine area. The timber on the Powell

[4] Diameter at breast height (4.5 feet).

tract is typical of second-growth longleaf as it occurs in the flatwoods region.

The trees on the Powell tract are longleaf pine, with the exception of half a dozen slash pines which were not included in the test. In 1923, the age of the trees ranged from 19 to 37 years, averaging 24 or 25 years. There were 40 to 50 trees per acre of turpentine size on the tract, although the stand varied greatly in density. Diameters ranged from 9 to 14 inches at the time the trees were first chipped. Most of the area was under cultivation in 1900, and practically all of it had been cleared of old trees prior to that time, although it had not been completely stumped. Owing to the very open character of the stand, the trees were not very tall, ranging in height from 32 to 68 feet. The site index was 70 to 75 feet (at 50 years) on the cut-over part of the tract, or normal for the southern pine region. On the old-field portion it was 90 feet. Fires probably occurred on this area four years out of five prior to 1923, when the experiment was started. Since that time, it has been the practice to rake around all the trees and to burn over the tract under supervision during the winter months. This has been necessary because of the impracticability of keeping fire out of so small a stand completely surrounded by lands burned annually.

The undergrowth on the Powell tract varies considerably in density. In the center of the area, where the timber stand is light, there is little or no underbrush but an abundance of dog fennel (*Eupatorium compositifolium* Walter). Broom sedge (*Andropogon* sp.) and other grasses form a thick mat where the trees are widely scattered. In the still more open spots dwarf oaks (*Quercus chapmani* Sargent and *Q. minima* Small), huckleberries (*Gaylussacia dumosa* A. Gray and *G. nana* (A. Gray) Small), blueberry, gopher apples (*Chrysobalanus oblongifolius* Michaux), and ground laurel are most common, with very little gall berry or palmetto, (*Serenoa serrulata* (Michaux) Hooker. Of the herbaceous growth, the most abundant species is deer-tongue (*Trilisa odoratissima* (Walter) Cass). Wire grass and a species of wild oats (*Sorghastrum* sp.) are the commonest grasses.

The Powell tract lies at an altitude of 150 feet above sea level, and the relative elevation above near-by cypress ponds on the southeast and north is probably about 5 to 8 feet. Ditches put in on two sides of the tract have resulted in good drainage except in one small corner of the area, in contrast with the poor drainage on the Sampson Lake tract.

The soil, which is decidedly variable, is classified in four soil series, the Norfolk, St. Johns, Leon, and Portsmouth. The texture is fine sand, with a few minor exceptions. The Norfolk soil has been described in connection with the Sampson area. The Portsmouth soil is fine sand of a dark-gray color to a depth of 8 inches, where it grades into light-gray loamy fine sand, usually saturated at a depth of 3 feet or less. The Leon soil has a hardpan of coffee-brown color at a depth of 10 to 24 inches; the gray fine sand surface soil is underlain by a subsoil of white or light-gray fine sand. The St. John soil is also a hardpan type similar to the Leon type, with a dark-gray fine sand surface soil over a light-gray or mottled gray and yellow sandy clay subsoil. This type is characterized by poor drainage.

GENERAL CONDITIONS AFFECTING YIELDS

WEATHER RELATIONSHIPS

Weather is an important factor in gum yields. It has been found that in midsummer 80 per cent of the weekly gum flow comes within 24 hours of chipping, whereas in the cold weather, the same percentage of flow may be spread over five days. Local weather records at Starke have been kept since the spring of 1925. Prior to that time, Jacksonville, 45 miles northeast, and Gainesville, 26 miles southeast, furnished the data needed. In general, the climate of this region may be classified as temperate, verging on the subtropical. (Fig. 4.) Table 1 shows the temperature and rainfall records for all four seasons. According to Jacksonville records, there was, over a period of 55 years, an average of 122 days each

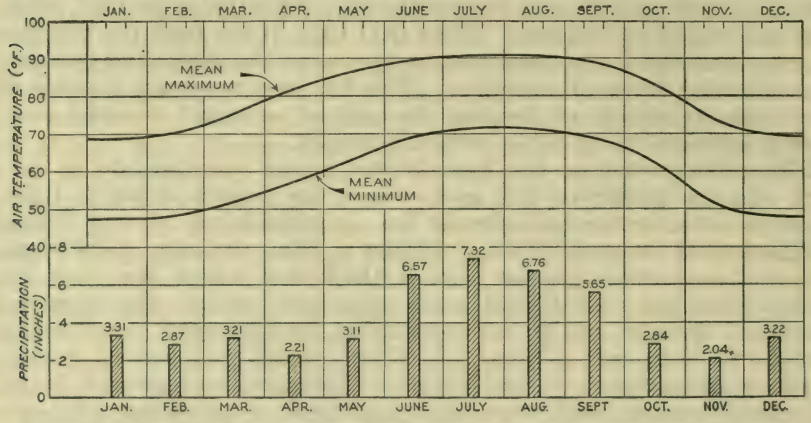

FIGURE 4.—Monthly mean maximum and minimum air temperatures (17 years) and total mean monthly precipitation (42 years) at Gainesville, Fla.

year with a measurable amount of rain; of these, 90 occur during the growing season. Gainesville records over a shorter period approximate these figures.

TABLE 1.—*Average seasonal maximum and minimum temperatures and precipitation, Gainesville, Fla.* (*30*)

Season	Temperature		Monthly precipitation
	Maximum	Minimum	
	° *F.*	° *F.*	*Inches*
Winter	69.1	47.2	3.13
Spring	81.1	57.5	2.84
Summer	90.2	70.1	6.88
Fall	81.9	60.6	3.51

Since no chipping is ordinarily done during the winter months, the weather during those months is of less importance than that during the rest of the year. Of the five chipping seasons (March to November, 1923 to 1927) during which the tests at Starke were being carried on, the wettest season was that of 1926 and the driest that in

1925. From March 22 to June 5, 1927, no rainfall exceeded 0.25 inch. This constituted a rather serious drought. The coolest seasons were in 1924 and 1926; the warmest, in 1927. The records indicate that 1926, with its cold, rainy weather, was the least favorable year for heavy gum flow, and that 1927, with its warm, relatively dry weather, was the most favorable during this 5-year period.

INDIVIDUAL VARIATION IN GUM YIELD AND SCRAPE

One of the most striking points that has come to light in the naval-stores experiments conducted by this station is the degree of variation which is found in the yield of gum from individual trees. It is not unusual to find trees alike in all external characteristics varying in their gum production by 100 per cent and in some cases even 300 per cent. This fact has also been noted in Spain by Cosculluela (*7*). Not only is it impossible to predict the gum-yielding capacity of individual trees by external characteristics, but it has also been found that, in the individual tree, the microscopic wood structure, as at present understood, can not be depended on to serve as a criterion of gum yields. This is a problem upon which Eloise Gerry is working.[5]

Large variations, particularly as between the two species, also occur in the amount of scrape formed on the face (*17*). An average of 6 per cent of the total seasonal yield of slash pine occurs in the form of scrape, and only occasional trees will run as high as 10 or 15 per cent; but longleaf pine averages 24 per cent of its total yield in this form. The economic importance of the proportion of scrape to total gum production can better be recognized when it is understood that, whereas the gum from the cups contains about 20 per cent or more of turpentine by weight, scrape contains only half as much. Because of the greater value of turpentine, slash pine, having the lower percentage of scrape, is the more valuable of the two species.

DRY FACING

Dry facing, although it is in the nature of a secondary effect of unregulated turpentining, nevertheless may quite as properly be attributed to the influence of environment and the habit of growth of the various trees in the stand and therefore can be regarded as a primary consideration influencing yield under various methods of turpentining. It is manifested in the form of a gradual drying out of the wood tissues, usually first appearing in the center of the face. No resin is produced on the particular area dry faced. Normally this drying out of the living wood tissue spreads until finally no gum is produced except at the very outside corners of the shoulders of the face.

There has been much misunderstanding about the nature of dry facing, and as a result little has been done to reduce it to the minimum that it should reach in any well-managed stand. It should be realized that the flow of gum as a result of the scarring of the outside wood serves to coat the exposed wood until healing tissue can be formed and bark built up to cover the scar permanently. Under natural conditions the success with which this healing process can

[5] Reported in a paper presented before the American Society of Plant Physiologists, New York, December, 1928, A Study of Externally Matched Southern Pines which Produce Widely Different Yields of Resin.

be completed depends altogether upon the health and vigor of the tree. One instance of the failure of this process is found in the case of the tree in a dense stand, which has failed in competition with other trees and has only a small crown area. Such a tree has not the vigor of a dominant or open-growing tree and consequently will not be so well able to respond persistently and effectively to the scarring of its bark and wood. Translated into the terms of the artificial process of chipping the tree for gum, this means that a tree lacking in vigor, as indicated by small crown or other evidences, will not be able to maintain the flow of gum that can be expected from a vigorous large-crowned tree. As it fails in this response the failure becomes evident in what we call dry facing.

Deep chipping, drought, and the chipping of trees that are too young have frequently been considered causes of dry facing. Operators who hold this view have based their opinions upon extensive observations (*3*, *5*, *16*, *20*, *21*, *24*, *27*, *28*, *35*, *37*). These are certainly contributing causes of dry facing, but it should not be forgotten that in every instance the lack of vigor of the tree is a major contributing cause and that a sturdy, full-crowned tree will withstand considerable abuse without dry facing.

As might be expected, dry facing is particularly troublesome in crowded stands where trees are less vigorous and have narrower growth rings and a narrower band of sapwood. When such trees are turpentined not only are they less able to maintain a constant response in flow of gum but also the effort exerted in response to the scarring evidently further weakens the tree. This cutting into a narrow band of sapwood interferes with the flow of sap, further reducing the vigor of the tree. Of 545 second-growth slash pine trees in a crowded stand 50 per cent exhibited some signs of dry facing at the end of the fourth year of work. In contrast, out of 1,075 slash pines growing in a more open stand on the same timber tract, only 34 per cent were dry facing at the end of the fourth year. All types of chipping were included in these stands. In two other groups of 150 slash pines each, all chipped in approved manner, only 29 per cent of the open-grown trees were dry facing at the end of the fourth year, in contrast with 40 per cent among the crowded trees.

Young longleaf trees with healthy crowns seldom dry face. However, dry facing may occur in young stands where trees through previous ill-treatment have suffered reduced growth and thus have only a thin layer of sapwood. Among old slash and longleaf pines serious dry facing is rather common, owing also to the narrowness of the sapwood which is easily cut through by heavy work.

Dry facing in itself may bring about serious loss to the operator and owner when it reaches so advanced a stage as to cause abandonment of work. This, however, is not the whole story. Dry facing is often only the first evidence of deterioration and is likely to be closely followed by insect damage, by the development of wood-rotting fungi, and eventually by the total destruction of the tree through windbreak. Even where the wood is not pitch soaked or destroyed it is very often attacked by blue stain, which causes the lowering of grade in lumber. In one record taken where dry faces in many trees showed blue strain superficially, it was found that

as a matter of fact practically every dry-faced tree had been attacked by blue-stain fungi.

No reference to dry facing has been found in any of the foreign naval-stores literature which has come to the author's attention, with the exception of one Russian article (*23*). Evidently it is uncommon or seldom occurs abroad.

WORKING TECHNIC

TREE SELECTION AND MEASUREMENT

In selecting the tree groups used in the various slash pine tests, strips approximately 1 chain (66 feet) wide were run from the edge of the lake back for 250 to 400 feet. For each of these groups, 50 unchipped trees over 8 inches d. b. h. and free from fire scars were selected. The groups, therefore, were located more or less on parallel strips somewhat overlapping each other, and with conditions comparable throughout.

The location of the 50-tree groups on the Powell tract differed from this. The practice on the longleaf tract was to concentrate all the trees worked under one style of chipping into one portion of the tract. After the groups were laid out, it was found that two of the groups in the height-of-streak test occurred on Portsmouth fine sand while the third group was partly on Norfolk fine sand and partly on St. Johns fine sand. The latter group is thus on soil which is somewhat better drained than that on which the other two groups occur. The three groups used in the depth-of-chipping test all occur on Norfolk fine sand.

Diameter measurements of all trees were taken at breast height and at 9 feet above the ground. The higher point was chosen so that a remeasurement of growth might be made at the end of the test period, above the scarring caused by all but the highest chipping. Height of tree and length of crown were measured, but average width of crown was estimated. Vigor of trees was classified as poor, medium, and good, most of the trees being classified as medium. Likewise, crown class was recorded; and crown density was recorded as being thin, medium, or thick, 75 per cent or more of the crowns rating as medium. Increment borings at breast height were taken on all trees in order to determine age and the number of rings in the outer half inch of wood. This width was chosen because it represented the depth of streak cut in all but two of the groups. Remeasurements were taken at the close of the test in 1927 in order to correlate growth or changes in tree condition with the variable under consideration.

FACING, CHIPPING, AND DIPPING

Facing was done by the regular crews employed by the two firms with whom the station was cooperating.

The method of facing the trees was the same on both the slash and the longleaf areas. At the start of the tests, tins or gutters were set in cuts made with broadaxes after a rather heavy slab of bark and wood had been removed. The thickness of this wood slab was 0.5 to 0.75 inch and the ax cut for tin insertion extended in another 0.5 inch. Sloping gutters and Herty clay cups were used. The removal

of the wood slab proved rather injurious, and the facing has since been modified to omit this.

The same method of raising tins was used in both the slash and the longleaf tracts. In the spring of 1924, and again in the spring of 1925, when the tins were pulled and raised to within 7 or 8 inches of the last streak of the preceding season, the tins were inserted in broadax cuts 0.5 to 0.75 inch deep, and one or more nails were used on each tin to hold it securely. In the spring of 1926, tins were tacked in place on the face, with no special preparation before tacking. It was deemed unpractical to raise the tins and cups for the last year of chipping.

The chipping season was started on or about March 15 each year. One streak was cut regularly each week, with only an occasional interruption due to lack of chippers, to weather conditions, or to other causes, until from 30 to 33 streaks had been cut. Season yields have been computed on a 32-streak season by adding or subtracting, where necessary, a proportionate amount of the last dip.

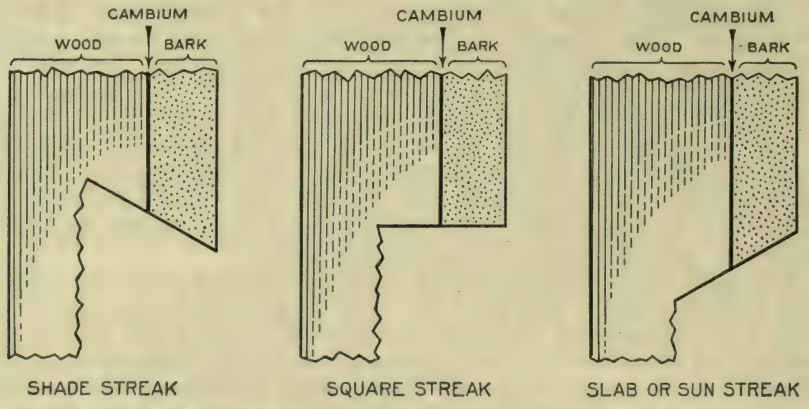

FIGURE 5.—Profile of turpentine faces, showing different types of streak

No. 0 hacks were used for all chipping except where wide streaks called for a No. 2 hack. The type of streak used is classed as a "square" streak by operators. (Fig. 5.)

The chipping specifications were quite closely followed, and small leeway was allowed. Shoulders were kept even. Face widths were marked after the first year and every tree was inspected every week.

The cups were furnished by the operator. Grades of rosin, which might be affected by type of cup, were not determined during the period of operating these tests.

The gum was dipped from the cups during each chipping season whenever the cups were full on 20 per cent of the best producers. Where necessary, on a few trees which yielded an exceptionally large amount of gum, additional cups were placed between dips. A considerable number of the trees, however, had not completely filled their cups at dipping time.

WEIGHING

In 1925 the gum from each tree in each group was weighed separately at each dipping, but in the other four years the total dip only

was weighed. Water and trash, such as chips, bark, and leaves, were removed as far as practical, but some trash and water were unavoidably included in the gum weighed. At the end of the season, the hardened scrape on the faces was removed and weighed for each group, except in 1923, when not enough scrape had collected on the slash pines on the Sampson tract to warrant gathering.

Steelyard scales recording by ounces were used for weighing buckets of gum, and spring-balance scales recording by ounces and kept in careful adjustment were used for obtaining the weight of gum from individual trees.

ALLOWANCES

Gum analyses made in 1929 by the Bureau of Chemistry and Soils of 16 samples from similar tests at Starke showed a range of water content from 4.7 to 10.2 per cent, with an average of 6.8 per cent; and trash ranging between 1 and 4.1 per cent, with an average of 3 per cent. Analysis of 8 samples of scrape gave water ranging between 1 and 2.4 per cent, averaging 1.8 per cent; and trash between 2.1 and 4.2 per cent, averaging 3.3 per cent. Dip from commercial stilling operations near by had a water content of 11 to 12 per cent, and trash amounting to 2 to 3 per cent by weight. From these figures, it appears that the proportion of water was considerably higher in gum from commercial operations than in gum from the experiment station tests, whereas the proportion of trash and dirt was about the same. In later tests, in which a canvas chip paddle was used, the proportion of trash was reduced to about 0.6 per cent.

In the records of gum yield, allowance has been made for accidents such as occasional broken cups or gum wastage or trees not streaked for one cause or another. Such accidents were compensated for by adding a proportionate amount of gum to the group weighing. On the other hand, where trees have been killed by the type of chipping used on them, the group has been considered as a full group and no additional gum has been added to compensate for the loss of trees so killed. Adjustments in scrape yields were made by assuming that scrape was formed in proportion to the amount of face exposed successively as each new streak is put on. Temperature is known to affect the formation of scrape but, as definite figures on this point were lacking, no account of it was taken.

RAKING AND BURNING

Each December, pine needles, grass, and gum were raked from around all trees and the whole tract was burned. It was found not to be feasible to keep the experimental areas unburned, since they lay in the midst of timber tracts which burned every year and were so located that they could not be reached rapidly at short notice. In 1923, 1924, and 1925 the station staff burned the tracts. In 1926 and 1927 the tracts burned accidently subsequent to the raking, but without supervision. In the interval between raking and burning, leaves had blown in around several of the trees and so enabled the fire to reach the faces. In this way several of the faces were burned in each of these two years.

EFFECT OF METHODS OF WORKING ON STAND AND YIELD

HEIGHT-OF-STREAK TESTS

Height of streak, or the increase in length of face effected each time a new streak is put on, is of first importance in any general study of turpentining methods, because of its direct effect in limiting the period of working. In ordinary practice a ¾-inch streak is chipped, carrying the face up 2 feet or more a year and thereby usually terminating profitable chipping after five seasons' work. Obviously, lower streaks would allow a longer working to the same height of face. The principal question which height-of-streak tests must answer is whether gum yields by lower chipping would equal current yields and so warrant extending the chipping period beyond 5 years. If front faces can be worked from 7 to 12 years at anything like the average gum yield for 5 years, the result is bound to be of great significance and profit to the landowner, and hardly less to the operator.

The tests here described cover 5 years, but the trends which they clearly indicate give ample basis for estimating conservatively the results to be obtained from 7 to 12 years' work.

In the height-of-streak tests three groups of slash pine and three of longleaf pine, consisting of 50 trees each, were worked during a 5-year period, the three groups for each species being given, respectively, 0.75, 0.5, and 0.25 inch streaks. In each group, the width of face was kept uniform at one-third of the tree circumference at breast height, and depth of streak was 0.5 inch for all.

In the highest chipping group, the actual average height of streak was 0.73 inch, or very close to the 0.75 inch desired. The 0.5-inch height-of-streak test was chipped almost exactly to specifications. The 0.25-inch chipping deviated slightly from the desired height. In general, the streaks were kept down close to 0.3 inch, which is perhaps as near the quarter inch as could be attained on an average in any commercial operation. In 1926 and 1927 it seemed necessary to chip two heavy streaks at the beginning of the season in order to cut through the three-quarters to 1½ inches of wood that had become gum soaked over winter. This preliminary chipping increased the average height of streak to 0.32 inch.

Although one operator who has put 0.25-inch streaks on first-year work claims that the work took a third longer than the 0.5-inch chipping, the tests here recorded gave no evidence that the work was slowed down appreciably thereby, nor was any difficulty encountered in getting the work done properly.

The three groups of trees forming the slash pine height-of-streak test were closely matched as to diameter, height, age, and rate of growth, but not quite so well in size of crown, the high-chipping group having a crown width a little narrower than the other two. Comparative measurements are given in Table 21 in the Appendix.

The gum yield per group and the yield of turpentine and rosin per crop (10,000 faces) for the three styles of work included in the height-of-streak test are shown in Tables 2 and 3.

TABLE 2.—*Gum yield in relation to height of streak, slash pine, 32 streaks, 50-tree groups*

Year	0.32-inch streak		0.5-inch streak		0.73-inch streak	
	Yield	Loss	Yield	Loss	Yield	Loss
	Ounces	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*
1923	8,096		7,465		8,351	
1924	7,887	−209	7,084	−381	7,569	−782
1925	7,066	−821	6,832	−252	6,866	−703
1926	6,605	−461	6,088	−744	5,257	−1,609
1927	6,152	−453	5,504	−584	5,019	−238
Total	35,806	−1,944	32,973	−1,961	33,062	−3,332
		Per cent 24.01		*Per cent* 26.27		*Per cent* 39.90

TABLE 3.—*Calculated naval-stores yields per crop in relation to height of streak, slash pine, 32 streaks* [1]

Year	Turpentine			Rosin		
	0.32-in. streak	0.5-in. streak	0.73-in. streak	0.32-in. streak	0.5-in. streak	0.73-in. streak
	Barrels	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*
1923	57.5	52.0	58.8	175.6	162.7	181.5
1924	54.1	48.2	53.3	172.6	155.5	164.5
1925	48.0	45.8	46.2	155.0	150.5	151.2
1926	44.7	40.2	35.1	145.1	134.5	116.0
1927	39.8	34.4	31.8	136.8	123.3	112.1
Average	48.8	44.1	45.0	157.0	145.3	145.1

[1] Turpentine barrel contains 50 gallons; rosin barrel contains 420 pounds net. Bureau of Chemistry and Soils converting factors for turpentine yields used as follows: For 0.32-inch chipping, 21.9 per cent weight of dip and 9.2 per cent weight of scrape; for 0.5-inch chipping, 21.5 per cent weight of dip and 9.2 per cent weight of scrape; and for 0.73-inch chipping, 21.7 per cent weight of dip and 9.9 per cent weight of scrape. Water and trash for all groups, 6.7 per cent.

The first significant fact brought out in Tables 2 and 3 is that the 0.32-inch streaks yield quite as much as the 0.73-inch streaks. However, the true significance of the records is shown more strikingly in Figures 6 and 7 and is given a measurable value for operator and owner in the projected (dotted-line) bars of Figure 8.

The total of 225 barrels of spirits and 725 barrels of rosin produced by the 0.73-inch streak represents all that such faces can produce. The faces raised by 0.5-inch streaks can, however, be worked for at least two years more, producing an additional quantity of gum that may well bring the total naval-stores yields up to 275 barrels of turpentine and 950 barrels of rosin.

The trees chipped 0.32 inch can be worked a total of 11 or 12 years, greatly increasing the total yield. The operation is limited only by the falling off of the annual yield of turpentine to a point at which, under ordinary market conditions, turpentining no longer pays. This advantage in favor of the 0.32-inch chipping is, of course, increased in more open and more thrifty stands, where the initial year's yield is higher and a long period of profitable exploitation is correspondingly assured. A number of conditions unavoidable at the time these tests were made—such as not raising the cups in the fourth and fifth years, and the heavy ax cut made for tin insertion in the

first three years—have probably been responsible for increasing the decline in yield from year to year. Under more favorable and at the same time more normal conditions, there is little doubt that 0.32-inch streaks could be run up profitably for 12 years on a single face on timber that now yields a profit with 0.73-inch streaks.

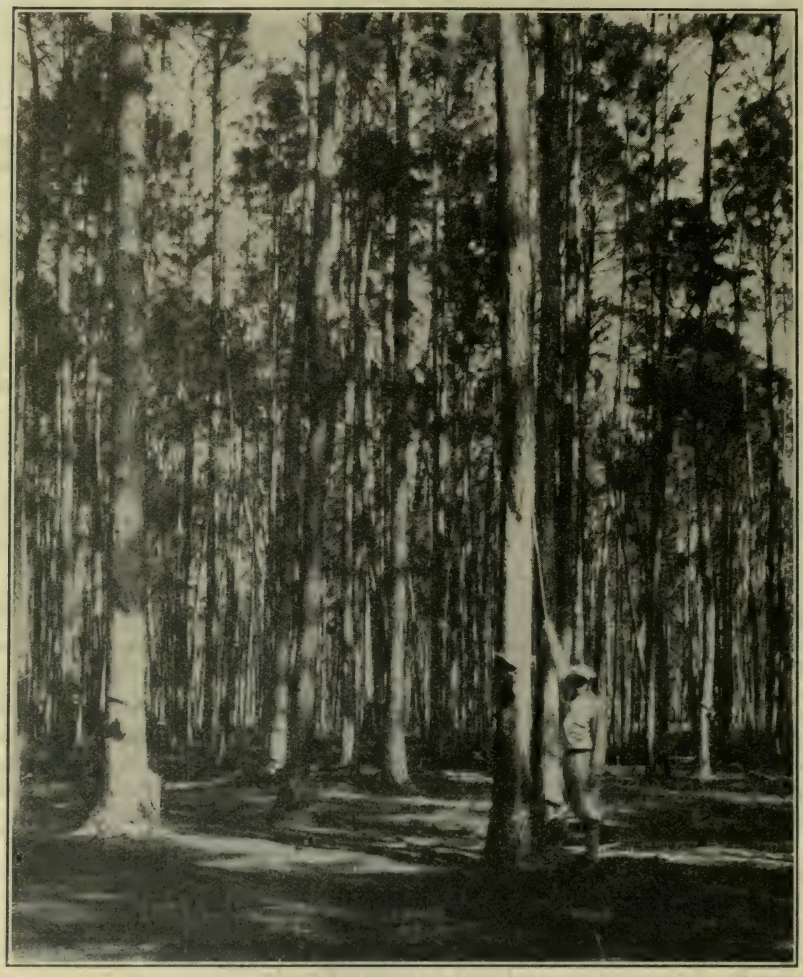

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FIGURE 6.—Height of faces at the end of five years of chipping slash pine with streaks 0.5 and 0.73 inch high. The tree on the right is worked out, the other may be chipped for two more years

On records now available through the 1929 season, 0.32-inch chipping extending over seven years has already yielded 322.9 barrels of turpentine, as against a total possible yield of 225.2 barrels for high chipping. A conservative estimate of the yield expected in the next three years is 105 barrels, bringing the expected total for 10 years of front faces up to 428 barrels. The faces will then be a little over 8.5 feet high or about two years short of their workable height.

The three groups of trees in the longleaf height-of-streak test were not exactly comparable except in density of stand, diameters, and width of face. The trees in the group chipped with 0.32-inch streaks were about 8 or 9 years older than the others and slower in

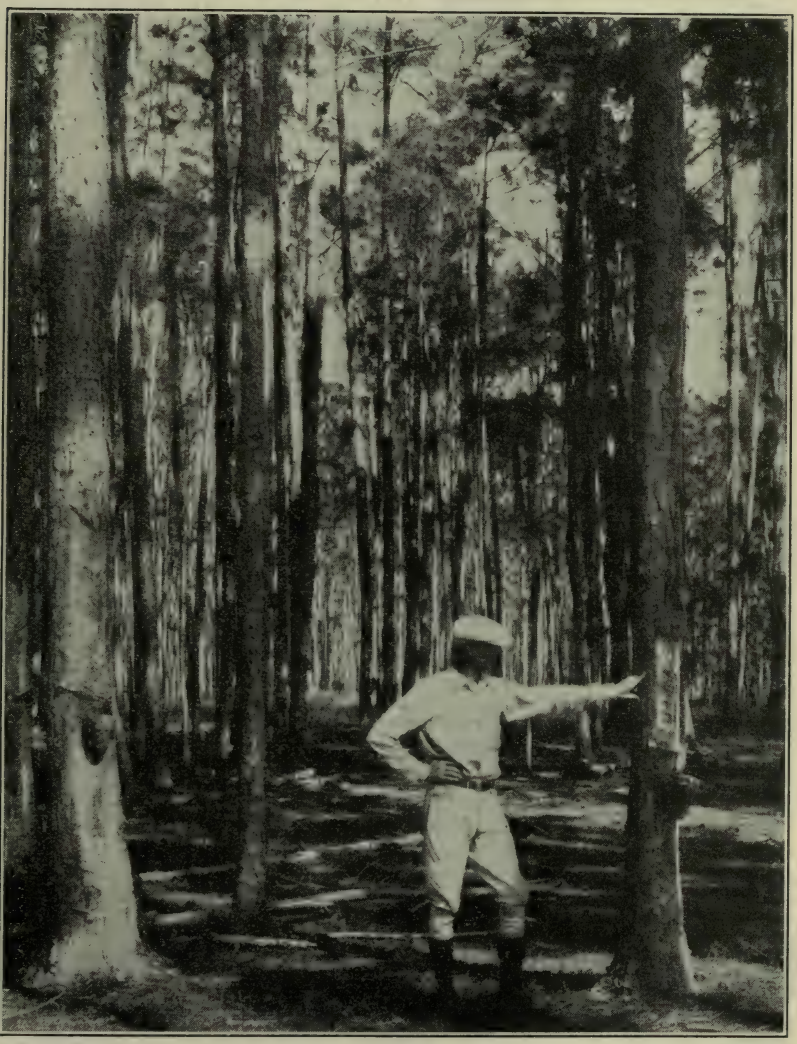

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FIGURE 7.—The two trees in the foreground show the height of faces of slash pine trees at the end of five years of work, that on the right being chipped with streaks 0.32 inch high, and that on the left with 0.5-inch streaks. Low chipping gave greater yields than medium or high chipping over a 5-year period. The low-chipped tree may be worked for five more years

growth rate. The 0.5-inch and 0.73-inch chipping groups are more closely comparable, although the trees chipped with heavy streaks were somewhat smaller than those with medium chipping. Table 21 in the Appendix shows the character of the trees in the three groups. The yields from these tests are shown in Tables 4 and 5.

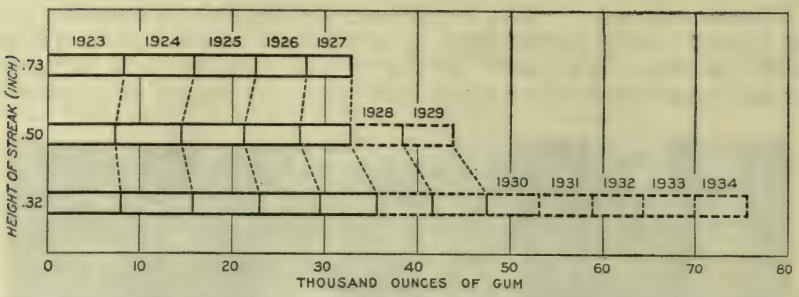

FIGURE 8.—Cumulative yields of dip and scrape on 50-tree groups of slash pine resulting from streaks 0.73, 0.5, and 0.32 inch in height. Yields are shown for five years of actual operation and as projected for the total number of years possible under the respective chipping heights. At the end of the three periods indicated all three faces have reached a height of about 10 feet

TABLE 4.—*Gum yields in relation to height of streak, longleaf pine, 32 streaks, 50-tree groups*

Year	0.32-inch streak		0.5-inch streak		0.73-inch streak	
	Yield	Loss or gain	Yield	Loss or gain	Yield	Loss or gain
	Ounces	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*
1923 [1]	6,033		6,905		7,127	
1924	5,138	−895	6,475	−430	6,791	−336
1925	4,720	−418	6,807	+332	6,075	−716
1926	5,016	+296	6,170	−637	5,238	−837
1927	3,449	−1,567	5,234	−936	4,712	−526
Total	24,356	−2,584	31,591	−1,671	29,943	−2,415
		Per cent 42.83		*Per cent* 24.20		*Per cent* 33.89

[1] Totals computed on a 32-streak basis from 22-streak yields actually measured the first year.

TABLE 5.—*Calculated naval-stores yields per crop in relation to height of streak, longleaf pine, 32 streaks* [1]

Year [2]	Turpentine			Rosin		
	0.32-in. streak	0.5-in. streak	0.73-in. streak	0.32-in. streak	0.5-in. streak	0.73-in. streak
	Barrels	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*
1924	32.4	42.8	43.7	113.9	141.8	149.8
1925	30.5	46.4	41.0	104.0	147.9	132.4
1926	33.8	40.2	34.7	112.3	135.6	114.6
1927	19.9	32.2	29.0	78.0	116.7	105.0
Average	29.2	40.4	37.1	102.0	135.5	125.4

[1] Turpentine barrel contains 50 gallons; rosin barrel contains 420 pounds net. Bureau of Chemistry and Soils converting factors for turpentine yields used as follows: For 0.32-inch chipping, 22.3 per cent weight of dip and 10.2 per cent weight of scrape; for 0.5-inch chipping, 22.9 per cent weight of dip and 11.2 per cent weight of scrape; and for 0.73 inch chipping, 22.9 per cent weight of dip and 10.9 per cent weight of scrape. Water and trash for all groups, 7.4 per cent.

[2] 1923 omitted because of incomplete record.

The yields from these tests indicate that the 0.5-inch streak is by far the most successful with longleaf pine. However, the fact that the 0.32-inch group was inferior to the other groups, especially in growth rate, makes it fair to assume that a more open and vigorous

stand would have given yields more nearly equal to those of the other groups. Here, as in the consideration of slash yields, the advantage of the longer working period allowed, for example, by the use of the 0.5-inch streak, is clearly evident. In seven years a total of nearly 250 barrels of turpentine would be obtained from this group, as contrasted with a total yield of less than 200 barrels from the 0.73-inch group. This superiority is well brought out in Figure 9, showing comparative gum yields.

It is interesting to compare with these figures the results of a similar test of height of chipping in mature longleaf carried out by Cary and Gerry (*15*) in northwest Florida in 1923. A report of the first year's work showed that low chipping (0.28 inch) gave about 9 and 12 per cent, respectively, more gum than either medium (0.45 inch) or high (0.71 inch). During the second year high chipping kept pace with low. Work by other investigators (*6*, *v. 35*, *no. 22; 29; 36*) brings out some interesting results, but they are hardly

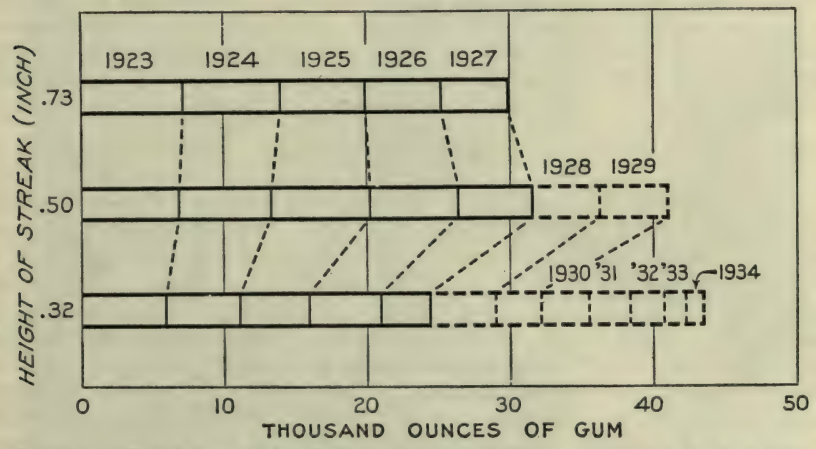

FIGURE 9.—Cumulative yields of dip and scrape in 50-tree groups of longleaf pine, from streaks 0.73, 0.5, and 0.32 inch in height. Yields are shown for five years of actual operation and as projected for the total number of years possible under the respective chipping heights

applicable to conditions in this region or are for other reasons not comparable.

In general, the results here shown indicate clearly the superiority of low or moderate chipping to high chipping in equal or greater annual yields, and still more in the additional working period per face allowed by the lower streaks. It is hardly too much to say that the operator who uses high chipping in either longleaf or slash is losing 25 to 50 per cent of the gum obtainable through more moderate chipping. In slash pine, where low chipping is clearly successful, his loss amounts to 50 per cent or more of the yield he can easily expect from front faces. Indeed, these tests, corroborated by evidence already available from further tests now under way, show plainly that high chipping can be justified only where the chipping will be immediately followed by the removal of the trees in a thinning operation or where the necessity of cutting trees for timber at an early date precludes the possibility of long-time turpentine

operations. Even here, the timber owner looking forward to cutting his stand within a few years may well consider the desirability of insisting on low chipping in view of the lessened damage to his trees. To the owner cutting poles or piles, a difference in height of face of more than 5 feet (representing five years difference between high and low chipping) has an appreciable money value.

An additional advantage in low chipping and consequent longer working life of the face lies in the longer healing period allowed before back cupping starts. The low chipping should appeal in particular to the operator who expects to work timber from the same location for a number of years and to the timber owner desirous of deriving maximum continuous returns from his land and timber. The continuous working of trees over an extended period will encourage the holding of timber until it reaches usable size for lumber or other high-grade forest products. The naval-stores operator will be enabled by such practice to keep his work within a smaller area or to increase his operation on the same area. This is a distinct advantage to him. For one thing, it will enable him to have workmen continuously in the woods, which will simplify fire fighting and detection. Also, it reduces his hauling costs and simplifies woods riding and inspection.

DEPTH-OF-STREAK TESTS

In the early days of the turpentine industry, according to McDougald (*25*), operators believed that deep chipping was necessary in order to obtain gum. As an example of this practice, a stand of young longleaf pine timber in Clay County, Fla., chipped with convict labor some 30 years ago, bears streaks averaging 1½ inches deep. This was not so unusual as to cause comment at the time the trees were chipped; and since it is more difficult to cut a deep streak than a shallow one, the operators of those days must have believed that a chipper must "get the wood" if a good yield were to be obtained. In later years shallower work has been more general.

Depth of chipping is of main interest to the timber owner, for whom it is only too readily reflected in degree of dry facing (fig. 10), blue stain, insect attack, and mortality of stand, all of which greatly impair the value of his timber for subsequent lumber or pole production. Mechanical weakening caused by deep chipping also results in considerable loss from subsequent heavy windstorms.

The purpose of the tests begun at Starke in 1923 was to determine the depth of chipping which, without serious loss in gum yields, would do least harm to the tree. Like the height-of-streak tests just described, the depth-of-chipping tests extended over a 5-year period. The general character of the timber chipped was also the same as that used in the height-of-streak tests. Four groups of 50 trees each were chipped in both slash and longleaf stands to depths of 0.3, 0.5, 0.75, and 1 inch, measured from the inside of the bark radially in a horizontal plane to the deepest point in the cut. Width of face in each group was standard, one-third of the tree circumference. Height of streak was the same in all groups, 0.5 inch.

Both slash and longleaf groups were closely matched, as is shown in Table 22 in the Appendix, and were in fact safely within the

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FIGURE 10.—Deep and ragged chipping has dry faced this slash pine tree

allowable limits of error. The slash pine trees were, however, rather crowded, with crowns somewhat smaller than desirable for best gum yields. The longleaf trees growing in a moderately open stand had larger crowns.

The No. 0 hack was used on all tests. Some difficulty was encountered in getting 1-inch deep chipping, and perhaps 20 per cent of the chipping which should have been 1 inch deep was only seven-eighths of an inch. The 0.75 and 0.5 inch deep chipping was done according to specifications. The shallowest chipping actually averaged about 0.3 inch, with occasional streaks exceeding that depth.

The ax cuts made for tin insertions in the spring of 1924 and 1925 doubtless increased the damage done by turpentining and seriously vitiated the results of the shallow chipping, and reduced the significance of the yields. However, the injury was equally severe in all groups, so that any difference in damage or yields in this test can safely be attributed to difference in chipping methods.

Tables 6, 7, 8, and 9 give the yields of gum, turpentine, and rosin obtained for slash pine and longleaf.

TABLE 6.—*Gum yields in relation to depth of streak, slash pine, 32 streaks, 50-tree groups*

Year	0.3-inch streak		0.5-inch streak		0.75-inch streak		1-inch streak	
	Yield	Loss or gain	Yield	Loss	Yield	Loss or gain	Yield	Loss or gain
	Ounces	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*
1923	6,795		7,465		8,291		8,091	
1924	6,288	−507	7,084	−381	7,046	−1,245	7,188	−903
1925	6,675	+387	6,832	−252	7,453	+407	6,815	−373
1926	6,056	−619	6,088	−744	5,370	−2,083	5,292	−1,523
1927	5,936	−120	5,504	−584	4,942	−428	5,601	+309
Total	31,750	−859	32,973	−1,961	33,102	−3,349	32,987	−2,490
		Per cent		*Per cent*		*Per cent*		*Per cent*
		12.64		26.27		40.39		30.77

TABLE 7.—*Calculated naval-stores yields per crop in relation to depth of streak, slash pine, 32 streaks*[1]

Year	Turpentine				Rosin			
	0.3-inch streak	0.5-inch streak	0.75-inch streak	1-inch streak	0.3-inch streak	0.5-inch streak	0.75-inch streak	1-inch streak
	Barrels	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*
1923	47.8	52.0	58.9	56.7	147.7	162.7	179.8	176.2
1924	44.3	48.2	49.2	49.4	136.7	155.5	153.6	157.3
1925	45.3	45.8	45.0	46.5	146.7	150.5	143.6	149.4
1926	40.4	40.2	36.6	35.8	133.6	134.5	117.7	116.2
1927	39.2	34.4	32.9	37.1	132.1	123.3	109.0	123.8
Average	43.4	44.1	44.5	45.1	139.4	145.3	140.7	144.6

[1] Turpentine barrel contains 50 gallons; rosin barrel contains 420 pounds net. Bureau of Chemistry and Soils converting factors for turpentine yields used as follows: For 0.3-inch chipping, 21.7 per cent weight of dip and 10.6 per cent weight of scrape; for 0.5-inch chipping, 21.5 per cent weight of dip and 9.2 per cent weight of scrape; for 0.75-inch chipping, 21.9 per cent weight of dip and 10.1 per cent weight of scrape; and for 1-inch chipping, 21.6 per cent weight of dip and 10.5 per cent weight of scrape. Water and trash for all groups, 6.7 per cent.

TABLE 8.—*Gum yields in relation to depth of streak, longleaf pine, 32 streaks, 50-tree groups*

Year	0.3-inch streak		0.5-inch streak		0.75-inch streak		1-inch streak	
	Yield	Loss or gain	Yield	Loss or gain	Yield	Loss or gain	Yield	Loss
	Ounces	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*
1923 [1]	5,960		6,905		6,337		6,706	
1924	5,130	−830	6,475	−430	5,329	−1,008	5,775	−931
1925	6,269	+1,139	6,807	+332	6,671	+1,342	5,583	−192
1926	4,793	−1,476	6,170	−637	4,945	−1,726	4,575	−1,008
1927	4,498	−295	5,234	−936	4,795	−150	4,461	−114
Total	26,650	−1,462	31,591	−1,671	28,077	−1,542	27,100	−2,245
		Per cent		*Per cent*		*Per cent*		*Per cent*
		24.53		24.20		24.33		33.48

[1] Totals computed on a 32-streak basis from 22-streak yields actually measured the first year.

TABLE 9.—*Calculated naval-stores yields per crop in relation to depth of streak, longleaf pine, 32 streaks* [1]

Year [2]	Turpentine				Rosin			
	0.3-inch streak	0.5-inch streak	0.75-inch streak	1-inch streak	0.3-inch streak	0.5-inch streak	0.75-inch streak	1-inch streak
	Barrels	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*
1924	34.8	42.8	34.9	38.9	111.7	141.8	117.0	125.6
1925	44.0	46.4	46.2	38.5	135.1	147.9	144.3	120.8
1926	32.9	40.2	33.1	30.6	103.9	135.6	108.0	99.9
1927	27.8	32.2	29.2	27.0	100.1	116.7	107.1	99.8
Average	34.9	40.4	35.8	33.8	112.7	135.5	119.1	111.5

[1] Turpentine barrel contains 50 gallons; rosin barrel contains 420 pounds net. Bureau of Chemistry and Soils converting factors for turpentine yields used as follows: For 0.3-inch chipping, 23.4 per cent weight of dip and 11.5 per cent weight of scrape; for 0.5-inch chipping, 22.9 per cent weight of dip and 11.2 per cent weight of scrape; for 0.75-inch chipping, 23.2 per cent weight of dip and 11.5 per cent weight of scrape; and for 1-inch chipping, 23.2 per cent weight of dip and 11.2 per cent weight of scrape. Water and trash for all groups, 7.4 per cent.

[2] 1923 omitted because of incomplete record.

As the tables indicate, there is little to choose, so far as total yield goes, between the different depths of chipping in either species, save that the 0.5-inch chipping of longleaf produced a considerably larger total than the other depths. In both species the 0.3-inch group is perceptibly lower in yield than the groups with deeper streaks, but on the other hand this group in the slash stand has decreased but 13 per cent in yield since the first year, as against 26, 40, and 31 per cent in the other groups. In the longleaf stand the percentage of decrease is not so favorable, but the trend of annual decrease in ounces of gum indicates that in another two years (such as would be entirely possible with the 0.5-inch height of streak used here) this group would easily equal and probably excel the 1-inch group in total yield. (Figs. 11 and 12.)

Meanwhile, all evidence goes to show that the deeply chipped groups (0.75 and 1 inch) are falling off in yield at a rate that would make seven years' work distinctly unprofitable as compared with the results of shallower chipping. The trend of a later series of tests bears out this contention.

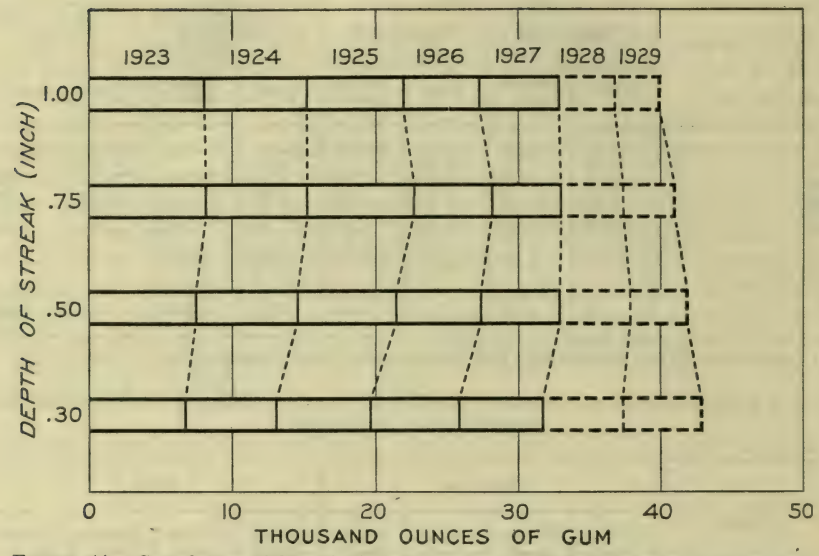

FIGURE 11.—Cumulative yields of dip and scrape on 50-tree groups of slash pine resulting from streaks 1, 0.75, 0.5, and 0.3 inch deep. Yields are shown for five years of actual operation and as projected for the two years of additional work possible with 0.5-inch height of chipping

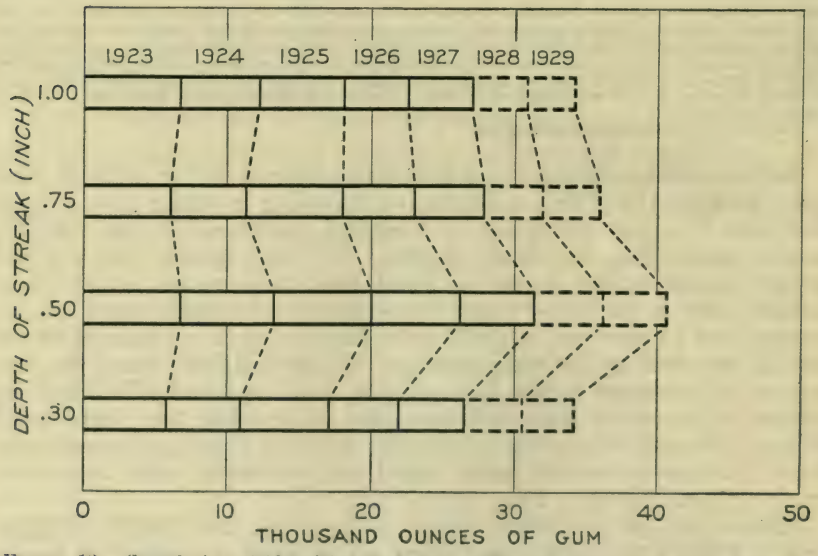

FIGURE 12.—Cumulative yields of longleaf pine similar to slash pine yields shown in Figure 11

The significance of these relationships lies in the assurance they give that there is no loss to the operator in the less destructive shallow chipping of 0.5 inch or less. The gain to the timber owner has already been mentioned.

Longleaf pine that is young and has plenty of growing space is not so easily injured by chipping as is slash pine. The mechanical weakening caused by deep chipping may, however, increase the mortality resulting from heavy windstorms. Further weakening is caused by the current practice, when raising cups, of cutting deep gashes in the old face with a broadax or gutter chisel for the insertion of tins. Dry face is a less material form of damage in longleaf, as has already been explained. Mechanical weakening with subsequent wind breakage can be avoided by the owner if he will specify shallow chipping for his timber.

In the dense slash stand in which these tests were made, the 0.3-inch group has 28 per cent of the trees partly dry faced, the 0.5-inch group 38 per cent, and the 0.75-inch and 1-inch groups 83 per cent each. These are the immediate results of depth of chipping, but, of course, they inevitably involve greater losses due to insect and fungus attack and eventual mortality. In more open stands of slash timber, such as commonly occur in the turpentine belt, the dry-face loss from shallow chipping would be reduced considerably.

The figure for percentage of dry face represents all trees having a measurable amount of unproductive wood in the streak, sometimes no more than 5 per cent of the producing area. Although less than 1 tree in 50 was dry facing so seriously that it was necessary to discontinue chipping, it is reasonable to expect that this proportion would be considerably increased were the operation to be extended beyond five years.

Nearly all of the slash pine that had dry faced by the end of the 5-year period became infected with blue stain, a combination of injuries which must result in degrade at the time the trees are cut into lumber. Unless logging takes place very soon, the dry face is almost certain to offer a point of access for boring beetles such as the turpentine borer (*Buprestis apricans* Hbst.) which is commonly found attacking slash and longleaf pines wherever dry wood is exposed. Other flat-headed borers and round-headed borers, getting into the dead wood, riddle the trunk and reduce the strength of the tree, thereby rendering it liable to windbreak as well as opening up a point of attack for wood-rotting fungi.

The results of these tests indicate that chipping to a 0.5-inch depth will yield as much gum as deeper work with considerably less damage to the timber; that in crowded stands of small-topped slash pine even shallower chipping is preferable, but that full-topped open stands of longleaf will stand a streak somewhat deeper than 0.5 inch without any undue injury.

WIDTH-OF-FACE TESTS

The facts to be determined by this series of tests included the width of face that would under ordinary circumstances produce the greatest gross yields; the most profitable face when cost of operation was figured in; the desirability of working two faces at once; and the practicability of back facing.

Roughly speaking, the success of the working is to be determined on the one hand by the actual increase of yield that may be gained by widening the face, and on the other by the effect of different degrees of scarring on the vitality of the tree, expressed primarily in dry facing and secondarily in the dying out of the trees.

In ordinary commercial turpentining operations the proportion of the tree girth cut away for a single face differs considerably but in a general way ranges from 30 per cent or less on 12-inch trees up to 45 per cent on 6-inch trees.

Two series of tests were performed on width of face. The first, extending over a period of five years, included single faces of one-fourth and one-half of the tree circumference and double faces totaling three-fourths of the circumference. The second, a 3-year test only, comprised single faces of one-fourth, one-third, and three-eighths of the circumference. Although the range of diameters covered several inches, the proportion of the circumference faced was the same in any one group.

Since it was impossible to locate suitable longleaf timber the experiment was confined to second-growth slash pine trees on the Sampson tract. The trees were growing under crowded conditions and in the first series a considerable number were small suppressed trees with poor tops. In such timber the effects of severe turpentining are accentuated.

In the first series of tests, groups of 50 trees were used for each width of face. Table 23 gives a comparison of the trees in the various groups. Trees in the intermediate group (50 per cent face) were slightly inferior in growth rate and crown size to the other two groups. However, on the whole, all are fairly well matched.

The gum, turpentine, and rosin yields obtained appear in Tables 10 and 11.

TABLE 10.—*Gum yields in relation to width of face, slash pine, 32 streaks, 50-tree groups*

Year	Single face—25 per cent		Single face—50 per cent		Double face—75 per cent	
	Yield	Loss or gain	Yield	Loss or gain	Yield	Loss
	Ounces	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*
1923	4,421		5,519		8,005	
1924	3,996	−425	4,366	−1,153	5,906	−2,099
1925	3,826	−170	4,526	+160	5,229	−677
1926	3,168	−658	3,559	−967	3,575	−1,654
1927	3,538	+370	3,633	+74	3,120	−455
Total	18,949	−883	21,603	−1,886	25,835	−4,885
		Per cent		*Per cent*		*Per cent*
		19.97		34.17		61.02

TABLE 11.—*Calculated naval-stores yields for 10,000 trees in relation to width of face, slash pine, 32 streaks* [1]

Year	Turpentine			Rosin		
	Single face—25 per cent	Single face—50 per cent	Double face—75 per cent	Single face—25 per cent	Single face—50 per cent	Double face—75 per cent
	Barrels	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*
1923	32.1	38.5	55.8	100.5	120.2	174.6
1924	28.4	29.4	39.0	91.3	96.1	130.8
1925	26.4	29.3	33.0	88.1	100.6	117.0
1926	21.8	23.6	22.6	73.1	81.4	80.0
1927	23.1	21.8	18.4	82.6	82.1	71.0
Average	26.4	28.5	33.8	87.1	96.1	114.7

[1] Turpentine barrel contains 50 gallons; rosin barrel contains 420 pounds net. Bureau of Chemistry and Soils converting factors for turpentine yields used are dip yields, 21.5 per cent turpentine by weight; scrape 9.2 per cent. Water and trash, 6.7 per cent.

It is evident from the figures given in Tables 10 and 11 that the gum yields from the three groups were not proportionate to the amount of scarring done. The low yields are attributable to the density of the stand and the small size of the trees (8 inches d. b. h.). Relatively higher yields may be looked for if the stands are more open and the average size of the tree is larger. Although the heaviest work involved cutting away three-fourths of the cambium, in contrast with one-half and one-fourth for the trees in the other groups, and the areas of exposed faces were practically in the ratio of 1:2:3; yet the yields obtained were in the proportion of 1:1.14:1.36.

One interesting point brought out is that the group with double faces actually produced less gum during the fifth year of working than either of the other two groups. A great deal of this loss in yield was a result of dry facing and tree mortality due to the heavy drain on the suppressed trees, caused by chipping. This damage is shown in Table 12.

TABLE 12.—*Effect of face width on tree vitality, at end of fifth year of working, second-growth slash pine*

Width of face	Trees dry facing	Trees dead
	Per cent	*Per cent*
25 per cent	54	12.5
50 per cent	76	16
75 per cent	94	30

These figures show increasingly heavy damage with greater face widths. The trees were in a very dense stand, and from 22 to 25 per cent of the trees chipped in each group were intermediate or suppressed trees having only a slow growth prior to turpentining. Under such conditions it is not surprising to find that over half of the trees with narrow faces showed dry facing at the end of the test. The injury from narrow faces would be much less on open-grown timber. For example, some back-faced slash pines in an open

stand at Sampson Lake had no trees killed by facing at the end of five years' work on the back faces, and only 29 per cent showed any signs of dry facing. Each face in this group was cut to one-third of the tree circumference. The significant point, however, in the tests here described is not the actual but the relative amount of injury done. Twice as many trees were drying out in the double-faced group as in the narrow-faced group.

Although the double face gives evidence of considerably greater total yield in five years, other considerations reduce this apparent superiority to negative values. In the first place, the additional area of wood exposed by the heavier cutting, which has a direct and proportionate effect on the vitality of the tree, is far out of proportion to the added yield. Furthermore, it must be considered that the 169 barrels of spirits gained from the 2-faced trees represents the total possible yield from these trees. No room is left for subsequent faces. Lastly, the advantage of the extra yield from the 2-faced trees is practically wiped out by the additional cost of working. To cut two faces simultaneously nearly doubles operating costs, whereas the yield from the 2-faced trees is only 36 per cent above that from the narrowest faces.

The 50 per cent faces can be operated practically as cheaply as the 25 per cent and with a somewhat greater yield. From the standpoint of immediate returns, therefore, the operator might feel justified in putting on wide faces. From the standpoint of the timber owner, however, there is no justification, because the possibility of placing future faces on trees which have been half girdled has been considerably reduced. It is possible to put another 25 per cent face on the trees with narrow faces and later a third face of the same width, but the wide-faced trees (50 per cent) will carry but one other set of narrow faces and will then have bark removed to the extent of at least 75 per cent of the circumference, or the equivalent of the three sets of faces on the original narrow-faced group.

Such records as are available indicate a slightly smaller yield from back faces than from front faces. In view of the fact that back-face yields are not much lower than front-face yields, however, and then only during the first year or two, it is believed that a third set of faces will yield nearly as much as the second set, assuming all faces on the same tree to be of the same width. Increased tree growth tends to offset increased scarring unless the trees are suppressed or decadent. It is estimated that the 25 per cent group in this crowded stand should yield annually an average of 24 barrels of spirits per 10,000 trees from the second set of faces and at least 24 barrels per year from the third set, which, when combined with the average annual production of 26.4 barrels from the first set, would give a total of 372 barrels, supposing that the chipping possibilities of the trees were exhausted by five years' working of each face. The 50 per cent group could be given a narrow second face which should yield 24 barrels of spirits per 10,000 trees annually or a total of only 262.5 barrels in the two 5-year working periods. These returns would of course be considerably greater in a stand composed of larger and more open-growing trees, where annual yields are higher and faces can be worked by low chipping for 7 to 12 years; but even these yields show a decided advantage in favor of narrow faces.

The second series of tests in the width-of-face experiment was a slight modification of the first, involving a narrower range of face widths and dispensing with the 50 and 75 per cent faces which caused so much damage.

This series, started in 1924, involved the placing of faces of one-fourth, one-third, and three-eighths of the tree circumference.

The trees used in this test had already been worked for one and one-half years with faces covering one-third of the circumference. For one quarter of the trees the face width was decreased to one-fourth of the circumference, for another quarter it was increased to three-eighths. The remaining trees were left unchanged.

The groups were worked for the remainder of the second year before yield comparisons were made. The narrow-faced and wide-faced groups were each composed of 25 trees. The intermediate group was made up of 50 trees. Comparable records of yield are available for the third, fourth, and fifth years only. Chipping was 0.5 inch deep by 0.5 inch high, one face to a tree.

The tree measurements of these groups are given in Table 23. In most respects the groups were closely comparable. No trees smaller than 8.2 inches d. b. h. were used in this test, so that in contrast with the preceding test there were few intermediate and suppressed trees. Gum, turpentine, and rosin yields for the 3-year test period are shown in Tables 13 and 14.

TABLE 13.—*Gum yields in relation to width of face (third to fifth year chipping) slash pine, 32 streaks, 25-tree groups*

Year	25 per cent face		33⅓ per cent face [1]		37½ per cent face	
	Yield	Loss or gain	Yield	Loss	Yield	Loss or gain
	Ounces	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*
1925	2,835		3,416		3,339	
1926	2,847	+12	3,044	−372	2,861	−478
1927	2,831	−16	2,752	−292	3,106	+245
Total	8,513	−4	9,212	−664	9,306	−233
		Per cent		*Per cent*		*Per cent*
		0.14		19.44		6.98

[1] Originally 50 trees in the group, but yields were halved and the group considered as a 25-tree group for purposes of comparison.

TABLE 14.—*Calculated naval-stores yields per crop in relation to width of face (third to fifth year chipping) slash pine, 32 streaks* [1]

Year	Turpentine			Rosin		
	25 per cent face	33⅓ per cent face	37½ per cent face	25 per cent face	33⅓ per cent face	37½ per cent face
	Barrels	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*
1925	37.6	45.8	44.6	124.5	150.5	147.3
1926	38.1	40.2	37.9	125.5	134.5	126.4
1927	35.4	34.4	38.7	126.0	123.3	139.4
Average	37.0	40.1	40.4	125.3	136.1	137.7

[1] Turpentine barrel contains 50 gallons; rosin barrel contains 420 pounds net. Bureau of Chemistry and Soils converting factors for turpentine yields used are dip yields, 21.5 per cent turpentine by weight, and scrape, 9.2 per cent. Water and trash, 6.7 per cent.

In this test the average measurements in inches of the cross section of producing wood cut away for the three groups bear the ratio of 1:1.20:1.41, whereas the ratio of yields is 1:1.08:1.09. This bears out in general the conclusion reached in the first series, that yields do not increase in the same ratio as increase in face widths or, more properly speaking, producing surface. In the first series face width and producing surface are proportional, but this is not the case in the second series, in which much wider faces were used. In the narrow, medium, and wide faced groups there was no significant difference in the number of trees killed by chipping, but 64, 40, and 80 per cent of the trees, respectively, were injured to some extent by dry facing. These figures are not consistent, the medium faces showing less dry facing than the narrow ones. They do show the greatest damage to the widest faces, however, and are larger than the dry-face figures for open-grown back-faced timber, which amounted to only 29 per cent, although in that group 66⅔ per cent of the bark was cut in forming two faces.

The high yields of the second series as compared with the first series of 5-year tests are due partly to better spacing of trees and partly to the larger size and better crowns. Average yields indicate that no great increase in gum production may be expected from wider faces over a 3-year period where face widths range between one-fourth and three-eighths of tree circumference. However, they show that the yields from 25 per cent faces fall off far less from year to year than those from the wider faces.

With no marked increase resulting from wider faces, the question of placing back faces on the trees assumes a new importance.

Assuming that back faces will have a width of not more than one-third of the circumference measured at the time the trees were first chipped and, further, that bark bars between faces are uniform at one-twelfth of the circumference, it is patent that the narrow-faced group may have three sets of back faces placed without a growth period intervening, but that the trees with wider front faces will require a growth period before a third face can be put on. Such a delay, postponing future yields, means a lower annual profit (figured over the working life of the tree) because of greater carrying charges.

The effect of face width on the possibility of back facing naturally brings up the question of the yields which may be expected from back faces and their relation to front-face yields from the same trees.

Measurements of back-face yields from four groups of trees are available. The first test was made in open-grown slash pine. The 50 trees in this test are described in detail on page 32 under density of stand, the measurements appearing in Table 24.

The trees were chipped 0.5 by 0.5 inch, with face widths equal to one-third of the circumference. After being chipped for three years (1923–1925), they were back faced and chipped from 1926 to 1929. It should be noted that no rest was given the trees before the back faces were put on. The back faces were about 10 per cent narrower than the front faces for the first two years but at the beginning of the third year were widened so as to be comparable with the front faces in that year.

No advance streak was used with the back faces, such as had been put on the front faces four weeks ahead of the regular chipping sea-

son in 1923. In 1923 the trees averaged 10.8 inches d. b. h. They were really too small to support a back face under good turpentine practice, even though very fair yields were obtained. Making due allowance for the difference in face widths, the yields from back faces totaled only about 9 per cent less than front-face yields in three years.

The second group of trees was in a crowded stand which had been worked for four years in a manner similar to that just described, and was thereafter given a year's resting period. The back faces then started were of the same width as the front face and were worked similarly.

These trees are described (the dense B group) on page 33, and the measurements are given in Table 24. The average diameter (d. b. h.) was 10.5 inches.

A third group of 50 trees at Sampson Lake was back faced after two years of rest following four years of work on the front faces (1923–1926). These trees were 10.6 inches in diameter at breast height in 1923.

Finally, a fourth group of 223 rather open-grown slash pines at Sampson Lake were back faced in 1930, following five years operation on front faces (1925 to 1929, inclusive). The average diameter of these trees was 9.1 in 1925. These last two groups had advance streaks at the time the front faces and back faces were cut.

Gum and naval-stores yields are given in Tables 15 and 16 for the first three groups and gum yields only for the fourth. Although the yields from back faces during the first year were noticeably lower than the first-year yields from front faces, the second-year back-face yields were considerably higher than from second-year front faces in two out of three of the tests.

TABLE 15.—*Gum yields from front and back faces, slash pine, 32 streaks* [1]

Group	Face	First year	Second year	Third year	Total
		Ounces	*Ounces*	*Ounces*	*Ounces*
1	Front	8,028	7,373	7,791	23,192
	Back	5,909	6,669	7,477	20,055
2	Front	7,738	6,219	7,114	21,071
	Back	5,310	6,850	6,680	18,840
3	Front	7,781	6,138	----------	13,919
	Back	6,745	7,225	----------	13,970
4	Front	26,862	----------	----------	26,862
	Back	22,680	----------	----------	22,680

[1] Groups 1 to 3 consisted of 50 trees each; Group 4 of 223 trees.

TABLE 16.—*Calculated naval-stores yields per crop, front and back faces, slash pine, 32 streaks* [1]

Group	Class face	Turpentine				Rosin			
		First year	Second year	Third year	Average	First year	Second year	Third year	Average
		Barrels	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*
1	Front	55.9	49.6	51.2	52.2	175.0	162.1	172.5	169.9
	Back	36.7	40.0	49.1	41.9	121.8	137.8	162.0	140.5
2	Front	53.9	43.3	47.6	48.3	168.7	135.6	156.7	153.7
	Back	35.6	44.7	44.1	41.5	114.5	148.7	144.5	135.9
3	Front	54.3	42.1	----------	48.2	169.6	134.3	----------	152.0
	Back	44.1	47.7	----------	45.9	143.3	156.1	----------	149.7

[1] Bureau of Chemistry and Soils converting factors for turpentine yields used are dip yields, 21.5 per cent turpentine by weight and scrape 9.2 per cent. Water and trash, 6.7 per cent.

In every case, the difference between first-year front-face and back-face yields was markedly reduced thereafter, to such a degree that for three years of working the back-face yields underran the front-face returns by only 11 per cent. Additional data may reduce this difference somewhat, since Groups 3 and 4 made a relatively better showing during the back-face periods than did the first two groups. The indication is fairly clear that back faces worked over longer periods in vigorous open stands will attain total yields very close to front-face yields. Indeed, with a 12-year working period per face, well-spaced trees should grow 1½ to 2 inches in diameter during the chipping period. This increase in size should result in greater yields from the second installation of faces than from the first set.

The width-of-face and back-face tests may be summed up briefly, as follows:

Relatively narrow faces, which cut away not more than one-third of the bark perimeter, maintain a relatively high gum yield over a longer period of operation than do the wider faces.

The trees with narrow faces suffer less from dry facing, and fewer trees die.

Wide-faced trees can not support three or possibly even two faces in rotation without rest periods. Such rest periods constitute a delay that means increased costs in the turpentining of the wider faced trees.

Although back faces yield somewhat less than front faces, the difference is not great.

Two faces worked at one time fall far short of yielding as much as two faces worked in rotation.

RELATION OF STAND AND TREE CONDITION TO TURPENTINING WORK

EFFECT OF DENSITY OF STAND, CROWN AREA, AND GROWTH RATE ON YIELDS

The effect of density of stand, crown area, and growth rate on gum flow (*42*) are so closely interrelated as to make any separate discussion of them difficult. Their combined influence is apparent both in yield of gum and in vigor of faced trees. Yields are manifestly lower in dense stands where many of the trees have inferior crowns and are therefore more easily injured by heavy working. (Figs. 13 and 14.) As indicated by some of the studies already discussed, thinning out dense stands by cutting or by purposely turpentining destructively the trees not desired in the stand, may greatly increase the yield per face on the released trees.

Most second-growth stands in the turpentine belt are not completely stocked with trees, but as fire protection and better forestry practices become more general, they will tend gradually to become more crowded. For this reason, it is important to know the effect of the spacing of the trees upon gum yields. To this end experiments in both longleaf and slash pine stands were begun in 1923, at the same time that most of the other turpentining tests were started.

Three groups of 50 trees each were used for the slash pine test. Two of these, designated as "dense A" and "dense B," were in a crowded stand of second growth, while the third group was in a somewhat more uneven-aged open stand on the same tract. In the

longleaf pine stand, two groups of 50 trees each were chipped alike to determine the effect of crowding upon production of naval stores. One of these groups was in a rather crowded stand, and the other was made up of open-grown trees of about the same age.

The chipping practice was uniform in all groups for both species, the streaks averaging 0.5 inch deep and 0.5 inch high. Faces covered one-third of tree circumference, and streaks were put on regularly once a week during the period covered by the experiment. Table 24 gives the average tree measurements for the groups which composed these two tests.

In the slash pine test, the trees in the dense B group were somewhat smaller in crown size and slower in rate of growth than in the dense A group. As might be expected, both dense groups were much poorer in crown development and growth rate than the open group. Also, in order to obtain open-grown timber of the same diameter, it

F—174254

FIGURE 13.—Open stand of 26-year-old slash pine on the Sampson tract.

was necessary to select trees somewhat younger than the trees in the crowded stand. The trees in the open stand included only dominant trees or those free from side competition. With this type of selection, it is impossible to determine exactly the average number of trees per acre, but by computing the average area of crown space occupied by these trees and dividing it into the number of square feet in an acre, a rough estimate of density of stand may be indicated. This shows that the open stand would contain 44 per cent as many trees per acre as are in the dense A group and 29 per cent as many as in the dense B group.

The longleaf stands have had a somewhat different history from that of the slash pine. (Figs. 15 and 16.) In the longleaf tract, the trees are practically even aged and comparatively young. For about 20 years all the longleaf trees had plenty of room to develop, and it was only during a very few years prior to the start of these tests that the tree canopy in the dense stand became sufficiently

F–174258

FIGURE 14.—Dense stand of 35-year-old slash pine on the Sampson tract

crowded to affect crown development. The open-grown trees were still isolated when the test began.

The dense stand of slash pine averaged 9 years older than the open-grown trees. It had always been much more crowded, which had

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FIGURE 15.—Open stand of 26-year-old longleaf pine, Powell tract. Trees with plenty of growing space yield well

resulted in a lack of sufficient space to develop crowns for 8 or 10 years before the present tests were started. On the other hand, the open-grown slash occurred in an uneven-aged stand where the trees

F—174261

FIGURE 16.—Dense stand of 27-year-old longleaf pine, Powell tract

selected for this test had been growing somewhat faster and had reached the same size as the trees in the dense stand at an earlier age.

There is a greater difference between the two longleaf stands than appears from the measurements recorded. (Table 24.) The open stand had but 74 per cent as many trees per acre as the crowded

stand. The longleaf occurs on a much drier situation than the slash groups, and where the competition for soil moisture and food materials is much keener.

Gum and naval-stores yields in relation to density of stand are given in Tables 17, 18, 19, and 20.

TABLE 17.—*Gum yields in relation to density of stand, slash pine, 32 streaks, 50-tree groups*

Group	1923	1924	1925	Total yield	Reduction in yield
	Ounces	*Ounces*	*Ounces*	*Ounces*	*Ounces*
Dense A (170 trees per acre)	7,465	7,084	6,832	21,381	633
Dense B (260 trees per acre)	7,738	6,219	7,114	21,071	624
Open (75 trees per acre) [1]	8,028	7,373	7,791	23,192	237

[1] Estimated from total crown area.

TABLE 18.—*Calculated naval-stores yields per crop in relation to density of stand, slash pine, 32 streaks* [1]

Year	Turpentine			Rosin		
	Dense A	Dense B	Open group	Dense A	Dense B	Open group
	Barrels	*Barrels*	*Barrels*	*Barrels*	*Barrels*	*Barrels*
1923	52.0	53.9	55.9	162.7	168.7	175.0
1924	48.2	43.3	49.6	155.5	135.6	162.1
1925	45.8	47.6	51.2	150.5	156.7	172.5
Average	48.7	48.3	52.2	156.2	153.7	169.9

[1] Turpentine barrel contains 50 gallons; rosin barrel contains 420 pounds net. Bureau of Chemistr and Soils converting factors for turpentine yields used are dip yields, 21.5 per cent turpentine by weight, and scrape, 9.2 per cent. Water and trash, 6.7 per cent.

TABLE 19.—*Gum yields in relation to density of stand, longleaf pine, 32 streaks, 50-tree groups*

Group	1923 [1]	1924	1925	1926	1927	Total yield	Reduction in yield
	Ounces	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*
Dense (135 trees per acre)	6,614	4,693	5,088	3,893	3,779	24,067	2,835
Open (100 trees per acre) [2]	6,905	6,475	6,807	6,170	5,234	31,591	1,671

[1] 1923 yields computed from measured dip of 22 streaks only.
[2] Estimated from total crown area.

TABLE 20.—*Calculated naval-stores yields per crop in relation to density of stand, longleaf pine, 32 streaks* [1]

Year [2]	Turpentine		Rosin	
	Dense group	Open group	Dense group	Open group
	Barrels	*Barrels*	*Barrels*	*Barrels*
1924	30.5	42.8	103.2	141.8
1925	34.3	46.4	110.7	147.9
1926	25.3	40.2	85.6	135.6
1927	21.6	32.2	85.6	116.7
Average	27.9	40.4	96.3	135.5

[1] Turpentine barrel contains 50 gallons; rosin barrel contains 420 pounds net. Bureau of Chemistry and Soils converting factors used are dip yields, 22.9 per cent turpentine by weight, and scrape, 11.2 per cent. Water and trash, 7.4 per cent.
[2] 1923 omitted because of incomplete record.

The effect of crowding on slash pine can be seen in the difference in gum yields between the open and dense groups. The open group fell off in yield only 3 per cent by the third year, whereas the two dense stands showed a falling off of about 8 per cent in the same period. It is natural to expect that trees in the open stand should be affected less by chipping than trees in the dense stands.

Effects of crowding are much more strikingly apparent in the longleaf stand. At the end of five years the dense stand was already below the limit of profitable turpentining, but the open-grown trees could be carried through two to five years more before reaching that limit.

Similarly, whereas the 3-year gum yield of the open-grown slash is 9 per cent higher than the average for the two crowded slash pine plots, in the longleaf test for the first three years (the first being approximate) the difference in gum yields is 23 per cent in favor of the open-grown timber; for the five years of the test this difference increased to 31 per cent.

These results are corroborated by the evidence afforded by 223 slash pines on which the relationship between crown size and gum yield was noted. The relationship was worked out by computing the theoretical crown surface of each tree, assuming that this could be represented by the curved surface of a paraboloid with a height equal to the crown length and a width equal to the crown width. Having computed the number of square feet of theoretical crown surface for trees of different sizes, the average yield was plotted over the size of crown. In view of the fact that the trees with the largest diameters were also trees having the largest crowns as well as the widest faces, it was natural to expect that these trees would produce more than small-crowned narrow-faced trees. For this reason the total gum yield per face was divided by the width of face, and a figure representing the yield of gum per inch was obtained. This curve of yield in relation to crown surface is shown in Figure 17.

Clearly, an increase in size of crown results in an increased yield of naval stores. This increase is most rapid at the lower end of the curve and gradually becomes less significant with the trees of largest crown size. The curve, however, continues to rise as far as the data available in this study extend.

The advantages in favor of rapid-growing, large-crowned, widely spaced trees are even greater than the figures themselves indicate. Such trees not only produce more gum per face, fall off much less in yield from year to year, and are capable of producing profitable yields over a longer working period, but also on these trees the faces heal over more rapidly, dry facing is far less evident, and mortality attributable to turpentining is notably less.

At Sampson Lake, 584 slash pine trees were used in working out the relationship between gum yield and tree vigor as expressed by the number of rings of growth in the outer one-half inch of wood formed before turpentining. The results shown in Figure 18 indicate plainly that the faster growing trees are much better gum producers than the slower growing, within any particular tract where soil, drainage, and site are fairly uniform. This will not necessarily hold where growth conditions are variable.

Where possible, good naval-stores practice should allow for sufficient density in slash and longleaf stands in early years to result in

self-pruning of the trees to a height of 8 or 10 feet, insuring a clear length of bole as high as the face will extend. At this point, the stand should be thinned to allow ample crown spread and to produce thereby a high resin yield. Some operators may desire to prune

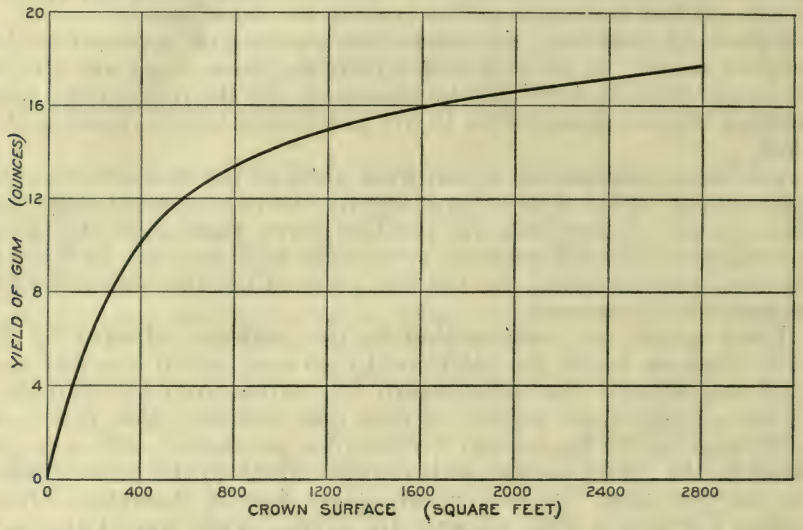

FIGURE 17.—Annual yield of gum per inch width of face in relation to crown surface, average of two years' chipping, basis 223 second-growth slash pines (chipping 0.5 by 0.5 inch, one-third circumference)

their trees by hand to a height of 16 feet while the stand is young, not only to improve resin yields but also to insure a high quality of lumber.

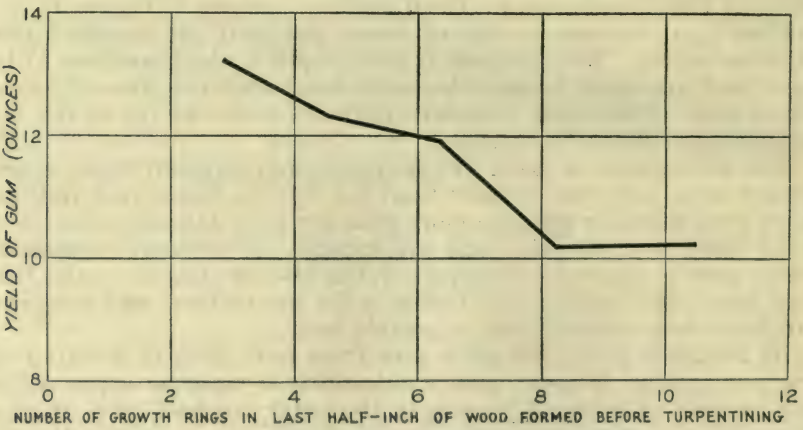

FIGURE 18.—Annual yield of gum per inch width of face in relation to growth rate. Basis 584 second-growth slash pines

It is not yet possible to state any definite conclusions as to the proper number of trees to grow per acre in order to make the greatest profit from naval stores. This number undoubtedly will be less than the best density for the production of the best quality of lumber.

GUM YIELD IN RELATION TO DIAMETER

The variation in gum yield with increase or decrease in size of tree is well recognized, but the actual proportions of this variation and the effect thereon of stand density and species have been mainly matters of conjecture. Largely because of this uncertainty, the meager profits or actual losses to the operator in turpentining small trees have gone unnoted, to the detriment of all concerned.

In testing the relation of tree diameter to yield, the commercial practice was followed of varying the width of face in proportion to the diameter of the tree. Faces were cut one-third of the circumference, measured at 4.5 feet from the ground. Three representative plots were chosen for the test, two of slash pine and one of longleaf.

The first of the slash pine plots, located on the Sampson tract, was an open second-growth stand of 223 trees ranging between 5.4 and 15.4 inches d. b. h. and including only dominants and codominants with fairly large crowns and little side competition for light and soil moisture. The second consisted of a dense stand of 139 slash pines ranging from 8.1 to 15.7 inches d. b. h., also on the Sampson tract, 38 years old, and even aged. Both stands were given 32 streaks 0.5 inch high and 0.5 inch deep. In the dense stand only the third-year work was measured by individual tree yields, but these may safely be compared with the 5-year averages from the open stand, since in the open stand the 5-year averages are practically identical with third-year yields. These relationships are shown in Figure 19 in terms of gum yield of dip and scrape, and in Figure 20 in turpentine yield per crop.

Because of the openness of the first stand, the small trees gave relatively good yields in contrast to those in the even-aged stand, where crown development was poor. The denser stand, however, produces in the graphs a steeper curve, which indicates that trees over 13 or 14 inches in diameter gave definitely larger yields than open-growing trees of the same size.

The high yields shown for small trees in the open stand deserve special comment. In ordinary practice, the Forest Service has generally assumed 25 barrels of turpentine per crop to be the lowest yield that will pay for working. According to that estimate, the data shown in Figure 20 apparently justify the chipping of trees as small as 6.7 inches in diameter. Several other considerations, however, which the chart does not reveal, must be taken into account, as they are of wide application in all operations where small trees are involved.

The first consideration is perhaps the effect on the tree, already indicated in the discussion of vigor of tree and its effect on yield. Although in open stands, 7-inch trees may yield 25 barrels or more per crop in the third year of work, as shown by the graph, not all will continue to yield to that extent in the fourth and fifth years. Only a small proportion will have a breadth and height of crown and general vigor that will enable them to support such work. In less open stands many will be killed out, and, as shown in Figure 20, in such stands no profits can be expected from trees under 8.5 inches.

Estimates given here are, moreover, based on an average market price for turpentine and rosin. With lower prices, as for example

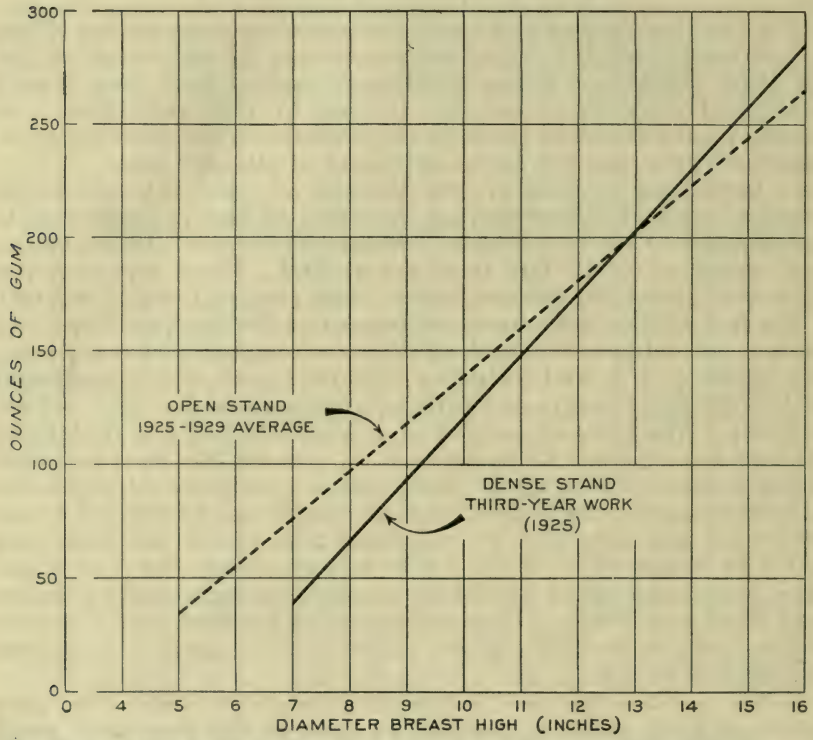

FIGURE 19.—Average annual slash pine yield of gum per tree (dip and scrape) for all diameters in open and dense stands of second growth; basis, 223 open-grown trees and 139 dense-grown trees chipped on single faces, 0.5 by 0.5 inch to one-third of circumference; 32 streaks

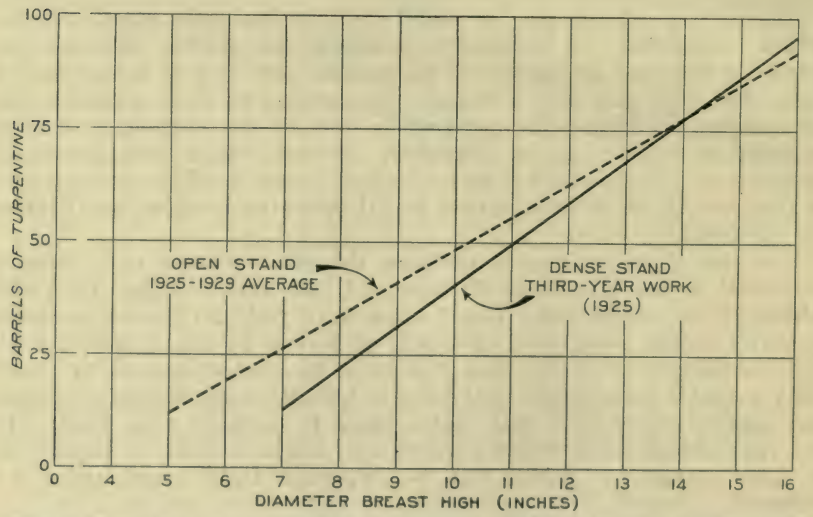

FIGURE 20.—Average annual slash pine turpentine yield per crop for all diameters in open and dense stands of second growth; basis, 223 open-grown trees and 139 dense-grown trees chipped on single faces, 0.5 by 0.5 inch to one-third of circumference; 32 streaks

in 1930, trees yielding less than 35 barrels would prove unprofitable, and the minimum diameter for working would be approximately 8 inches for a full-crowned tree in an open stand and 9 or 10 inches for any tree of less satisfactory development.

Another consideration is the stage of the operation. The minimum diameters given above may prove profitable or at least entail no great loss where the operation is already under way and overhead expense is distributed well over the work on the larger trees. To come into a new stand, however, and set up cups on trees under 9 inches in diameter, would be to run into serious losses.

The longleaf pine stand on which the relation of gum yield and diameter was studied was selected on a tract known as the Johns tract, the opportunity to work these trees being afforded through the cooperation of the owner, Merion Johns, of Starke. The timber comprises about 10 acres of second-growth longleaf with a scattering stand of slash pine in mixture and lies 2½ miles south of Starke in the flatwoods region. In density the stand may be described as fairly open. The trees ranged from 23 to 41 years of age in 1925. Measurements on the tract and on an adjacent old field indicate that growth conditions were above the normal or average for the South. This was further evident in the fact that although most of the trees above 10.5 inches had been boxed from 1911 to 1913 and the old faces burned, these boxed trees were making good growth. Fires had, however, been frequent and leaf litter was very thin.

This tract is about 140 feet above sea level and slopes gently toward a creek just to the north. The main part of it is 10 to 15 feet above creek level and is well drained. The soil is Leon fine sand. The ground cover consisted of gall berry, chinquapin (*Castanea nana*), dwarf oak, and scattered bunches of wire grass.

None of the boxed trees were used in the test, but all that were used had been worked for one year by a commercial operator. Face widths already determined averaged about one-third of circumference. No change was made in face widths, but streaks were brought down in 1925 to 0.5 inch deep and 0.5 inch high, from the somewhat heavier chipping of the commercial operator. Tins were raised in ax cuts on the face before the 1924 season started. The first streak was cut on March 23 and the thirty-second on October 10. The gum yield from each tree was recorded separately.

Altogether, 135 trees were used to make up the yield curve. Tree diameters ranged from 7 to 11.5 inches d. b. h. The yield curves in Figures 21 and 22, however, have been extended to 6 and 12 inches.

In comparing these curves with those shown in Figures 19 and 20 it should be noted that second-year yields on the Johns tract are a little higher than third-year yields on the Sampson tract. The second-year open-grown slash yields from the Sampson tract were, however, nearly 6 per cent higher than the average annual yields shown by the curves in Figures 19 and 20. A comparison of Figure 21 with the curve in Figure 19, as it would be if the values were increased by 6 per cent, indicates that gum yields from 10-inch slash and longleaf trees were identical. Longleaf trees smaller than 10 inches gave a slightly better yield of gum than the small slash, but the relation is reversed for trees larger than 10 inches in di-

ameter. Turpentine yields from 6-inch slash and longleaf trees are nearly alike, but for larger trees the slash pine proves to be a better naval-stores tree. In general, the turpentine yields from open-grown longleaf pine trees are lower than those from slash pine trees of the same size in the open stand, because of the larger proportion of scrape in longleaf, which yields less turpentine than does dip.

The results of the tests in this favorably located longleaf tract give no indication of any need to modify the recommendations made

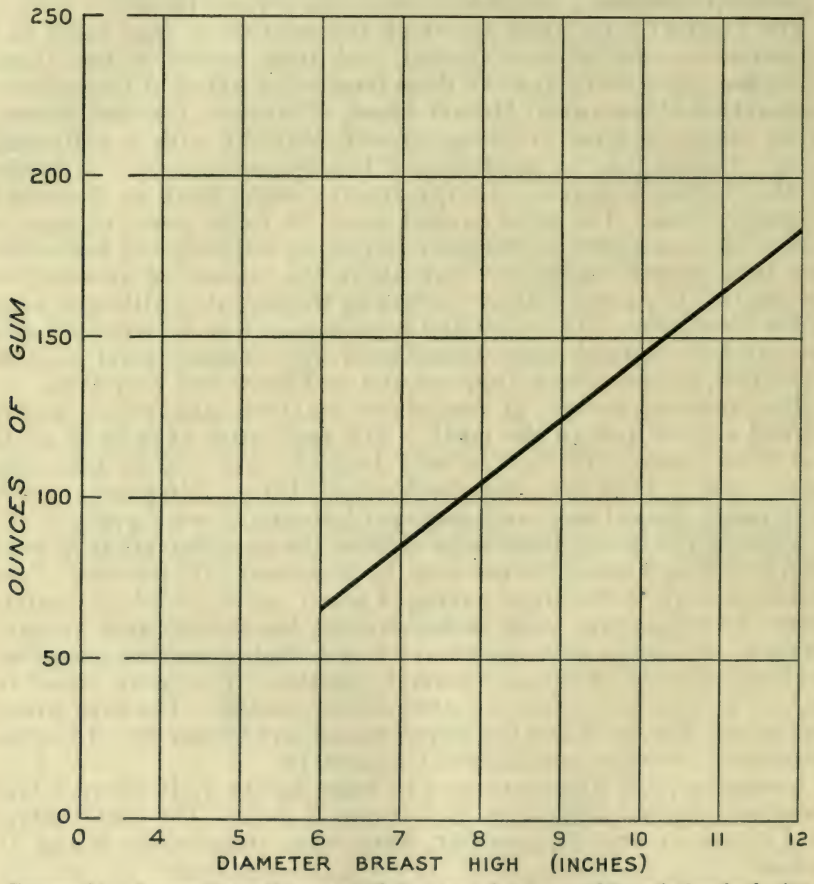

FIGURE 21.—Average anunal gum yield per tree from second-growth longleaf pine (dip and scrape) for all diameters; basis, 135 trees chipped on single faces, 0.5 by 0.5 inch to one-third of circumference; second-year work; 32 streaks

above, based on the slash pine tests. The minimum diameter for a yield of 35 barrels, based on second-year work, is 8 inches. In order to obtain a yield that would keep up to 35 barrels for five years the trees would have to be nearly 9 inches in diameter at the start. Only a favorable market for turpentine and a stand of vigorous, full-crowned trees would give warrant for working timber of less than 9 inches with any confidence of profit.

The results obtained by Cary on yield in relation to size of tree (*6, v. 33, no. 40; v. 34, no. 4; v. 35, no. 25; v. 38, no. 25*) are more or

less in line with the figures shown herewith, and indicate a direct relationship between gum yield and tree diameter.

EFFECT OF TURPENTINING UPON GROWTH

Timber owners are particularly concerned with the effect that turpentining has upon the growth of their timber, since they must balance loss in growth against the returns derived from the naval-stores operation. An example of what they may expect may be shown by comparing wood increment with naval-stores yields over a 25-year chipping rotation from trees first chipped when they are 9 inches d. b. h.

A 9-inch longleaf tree on a good site would be approximately 70 feet in height and would then scale 64 board feet by the international

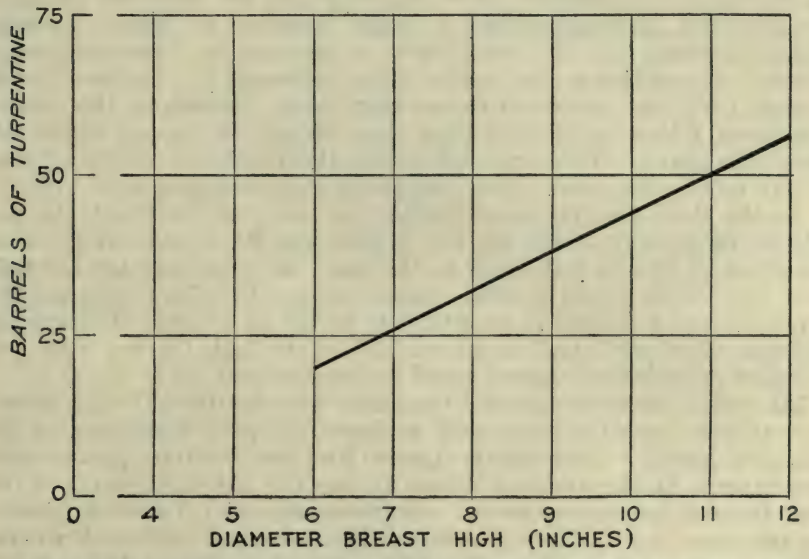

FIGURE 22.—Average annual turpentine yield per crop from second-growth longleaf pine for all diameters; basis, 135 trees chipped on single faces, 0.5 by 0.5 inch to one-third of circumference; second-year work; 32 streaks

rule (*39, p. 31*). Assuming that the tree would grow an inch in 5 years, it would in 25 years attain a diameter of 14 inches and a height of more than 90 feet. It would then scale 270 board feet, representing a volume of growth of 206 board feet, worth about $1 on a stumpage value of $5 per thousand feet. Such a tree might be chipped with streaks 0.5 inch high by 0.5 inch deep on faces each 25 per cent of the tree circumference in width for three periods of 7 years each, separated by two resting periods of 2 years each. The cupping value for these 25 years of operation would be estimated conservatively at 63 cents.

It is evident that decline in growth rate as a result of chipping may outweigh naval-stores returns on the better timber sites. Even on poorer sites, it is entirely possible for heavy chipping followed by fires to so ruin a stand that cuppage returns are more than offset by the decreased volume and value of the stand for lumber.

Any style of chipping affects growth to some extent. Cary (*6, v. 33, nos. 38 and 40; v. 35, no. 21; v. 38, nos. 26 and 27*) has shown that both diameter and height growth are adversely affected by turpentining, especially by the common practice of placing more than one face on moderate-sized trees.

Even conservative work, as practiced in France, has been shown to reduce growth. Buffault (*2*) quotes a report from Provence that maritime pine (*Pinus pinaster* Sol.) and Aleppo pine (*Pinus halepensis* Miller) have their growth reduced by 2 per cent at the maximum for "gemmage à vie" and 6 per cent for the severe "gemmage à mort." This is much less than Cary shows for American species.

On the other hand, Kienitz in Germany (*22*) claimed that tapping resulted in no actual decrease in total volume. Rings were as wide after chipping as before, although the cell walls were thinner. Weidemann (*41*) claimed that chipping had no effect on diameter growth, but perhaps caused a slight decrease in height growth. Some Germans (*34, 41*) even claim an increase in diameter growth during turpentining or immediately afterward. Schwerdtfeger claims that this amounted to one-third more growth in the five to six years following turpentining than during the period when the tree was round. These are, of course, the results of chipping that is far more conservative than anything recommended here.

In the slash pine height-of-streak test the growth rate at 4½ feet above the ground during the test period was 80, 82, and 27 per cent as great as it was just prior to the start of chipping, for the 0.32 0.5, and 0.73 inch streaks, respectively. In other words, the trees showed a decline in growth rate under all heights of chipping, but the effect was much more marked where high streaks were cut. Similar records for longleaf could not be obtained.

At 9 feet above the ground the slash trees in the 0.73-inch streak group were growing only half as fast during turpentining as the 0.5-inch group. Comparable figures for the 0.32-inch group were not taken. In the longleaf stands during the last three years of the test the 0.5-inch group made over twice as much diameter growth as the trees in the 0.73-inch group. The trees with 0.32-inch streaks were growing faster than the 0.73-inch group during this period, although they were distinctly inferior in the beginning.

It is apparent from these observations that the lower the chipping the less the growth is retarded, but that some effect will be evident with even the lowest streaks.

This is the conclusion reached by Gerry, who has shown (*12, 13, 14, 15*) that chipping usually reduces the width of ring above the face, although in certain old slow-growth longleaf trees the ring width may be the same or even wider after chipping. She has shown also (*15*) that not only do the wood rings average wider with 0.32-inch chipping than with 0.73-inch chipping, but also that there are many more resin ducts per unit of area following the narrow work.

Increased depth of streak affected the growth rate of the turpentined trees somewhat in the same way as did increased height of streak. In the slash pine tests, the growth rate in diameter at breast height during the turpentining period was reduced to 72, 83, 67, and 57 per cent, respectively, of the prechipping rate by the 0.3, 0.5, 0.75, and 1 inch deep chipping. Corresponding depths of chipping in

longleaf reduced the rate of diameter growth (d. b. h.) to 77, 90, 88, and 65 per cent. The 0.5-inch chipping had least effect on diameter growth at 4.5 feet above the ground, and 1-inch chipping had the greatest effect. No reason can be advanced to account for the relatively poor showing of the trees with shallow streaks. Similarly, the diameter at 9 feet above the ground showed a slower growth rate for the deeply chipped trees than for those with shallower work, in both species.

The effect of face width on slash pine tree growth was also determined. During five years of turpentining, three groups of trees on which faces covered 75, 50, and 25 per cent of the tree circumference had diameter growth rates in the ratio of 1 : 1.23 : 1.79, respectively. These measurements were made at 9 feet above the ground on a few selected trees of equal diameters in each group. This takes no account of the large number of trees in the wide-faced group which were actually killed. Briefly, the 50 per cent faces reduced diameter growth 31 per cent more, and the two faces (75 per cent of circumference) reduced it 44 per cent more, than did the narrow faces.

Cary also finds that double-faced trees grow slower than single-faced trees during the turpentining operations. Elsewhere (*6*, *v. 33*, *nos. 38 and 40; v. 35*, *no 21; v. 38*, *no. 27*) he gives the effect on tree growth of chipping one or more faces.

It is clear that some decline in diameter growth rate must be expected as a result of turpentining, but that this may be kept to a minimum by conservative methods such as low chipping, shallow chipping, and the cutting of relatively narrow faces.

EFFECT OF CHIPPING ON SEED PRODUCTION

The effect of turpentining upon the production of seed has been studied to some extent in connection with the various naval-stores investigations at Starke. Cone-count records have been kept for individual trees on two longleaf tracts. An analysis of these records indicates no difference in cone production between turpentined and unchipped trees in the same locality. It might be mentioned, however, that no seed count was made from the individual cones from turpentined and round trees, nor was the viability of the seed tested. The controlling factor in cone production seems to be spacing or the density of stand in which the trees occur.

It seems probable that a drain on the tree's food supplies, such as is effected by turpentining, would reduce the food available for seed production.

Kienitz (*22*) concluded that seed production of Scotch pine in Germany was not reduced by turpentining. On the other hand, Planke (*31*) showed that unchipped Scotch pine produced heavier cones with more seeds and a higher germinating percentage than similar trees worked for turpentine. Forest Service records bear out Kienitz' findings. Apparently the reduction in the food supply caused by chipping has not been serious enough to affect cone formation in the southern pines.

INSECT DAMAGE

A species of flat-headed borer, the turpentine borer (*Buprestis apricans* Hbst.), is one of the commonest insect enemies of the slash

and longleaf pines (*9*). The economic importance of these beetles was recognized in 1909 (*4*).

The adult beetles emerge from the trees in February and March in northern Florida. The female beetles, seeking favorable places to lay their eggs, are attracted to any exposed deadwood of pine trees. Where no turpentining has been practiced, they seek old fire scars, lightning scars, or possibly places where large limbs have broken off and exposed the heartwood. With the advent of turpentining, however, the beetles usually lay eggs on dry faces, on dry wood exposed as a result of the melting off of the gum coating during hot summer weather, in old ax cuts on faces where the wood is not covered by a protective covering of gum, or in checks on old burned faces. Forest entomologists believe that these beetles can not successfully attack faces which are well coated with gum.

The larvæ of this beetle spend three years boring in the pine heartwood before emerging as adults. Preliminary studies by the Bureau of Entomology indicate that the larvæ work for the most part in the band of wood where the heartwood and sapwood join. The borers extend their galleries a foot to a foot and a half up and down the tree, from the point of entrance. After these beetles have worked in a tree for a number of years it is weakened to such an extent that it becomes prey to the first heavy wind.

In an examination of some 11-year-old faces chipped 0.5-inch deep, 0.5-inch high, and about 12 inches wide on the Choctawhatchee National Forest, in western Florida, 24 per cent of the faces were found to have emergence holes caused by turpentine borers (*8*). In the same locality narrow French faces, 3.5 to 4 inches wide and concave in shape showed emergence holes on but 4 per cent of the trees. On both of these areas the trees had been protected from fire, and the old faces were fairly well covered with gum. In turpentined slash pines near Starke, where tins had been raised and inserted in ax cuts in the faces, 25 of the 50 trees observed were found to have been attacked by *Buprestis apricans* within two years after the raising of the tins.

The use of narrow faces and shallow chipping and the practice of tacking tins on faces rather than inserting them in ax cuts should prevent serious injury from borers, provided old faces are kept unburned.

Turpentined trees weakened or injured by heavy working or by floods, droughts, fires, or other causes may at times be attacked by various species of Ips beetles (*Ips avulsus* Eichh., *I. calligraphus* Germ., and *I. grandicollis* Eichh.) (*32*, *33*). Instances of epidemics of these beetles are not uncommon, but in practically every case the insects may be considered of secondary importance, the primary cause of death being other injuries.

During the last seven years of turpentining investigations by the Southern Forest Experiment Station in slash pine, only one instance has occurred where Ips beetles (*Ips calligraphus* Germ.) apparently killed a number of trees. This happened in the late fall and early winter of 1926. Preceding the attack, heavy rains in July and August, 1926, caused the water at Sampson Lake to rise until it stood around the trees to a maximum depth of 5 feet. A strip of timber

100 feet wide bordering the lake was under water for 10 weeks. As soon as the water receded, Ips beetles attacked a number of the trees, 26 of which died during November, December, and January.

On an adjoining area of similar timber chipped by a commercial operator, there was a very heavy loss of trees from these insect attacks. On this adjoining tract of land the timber had been chipped more than 1 inch deep. Every tree over about 8 inches in diameter was worked with two faces, whereas the station trees, except for one group, were being worked with one face only. The additional weakening effect of the second face on these trees, coupled with the deepness of the chipping, caused such a drain on the vitality of the trees that about one-third of the stand in a narrow strip along the lake was killed. A few round trees also were killed during this insect attack. This loss may have been the result of an accidental spread of the insects from turpentined trees. It is not usual for these insects even when very abundant to attack healthy, vigorous trees. Aside from this one istance of killing by Ips, only an occasional tree has been noticed as dying from insect attacks.

A study was made of all trees which died on the experimental turpentine areas and which had been attacked by insects prior to their death, in order to determine whether there was any relationship between bark-borer attack and the ability of a tree to produce a large quantity of gum. There seemed to be no general rule governing insect attacks, as some of the trees were very good yielders and others relatively poor.

Southern pine beetles (*Dendroctonus frontalis* Zimm.) seldom attack slash and longleaf pines. This may be accounted for by the fact that these two species of trees produce such a large amount of resin when wounded that beetles are drowned out before their weakening effect is sufficient to dry out the trees so that breeding will be possible. According to the division of forest insects of the Bureau of Entomology (*33*), epidemics of these beetles in the turpentine pine stands are extremely rare, although a few isolated cases are on record.

Among the insects which are found in turpentine stands but which do not kill or seriously injure the turpentine pines are sawfly larvæ (*Neodiprion lecontei* Fitch) which cause injury by defoliating the trees, and tip moths (*Rhyacionia frustrana* Comst.) which sometimes kill the terminal shoots and stunt the tree growth. Other insects attack the cones, but these have little or no effect upon gum yields and are not influenced by turpentine practices.

NORMAL MORTALITY OF TREES

The average annual death rate from all causes among the 919 slash pines worked for five years in these experiments was 1.31 per cent. However, a better normal-mortality figure may be obtained by excluding the heavily worked trees or those chipped with faces covering 50 or 75 per cent of the bark surface. The loss from all causes on the remaining 619 trees was 0.85 per cent per annum. On the same tract 1,100 other trees which had been turpentined for 4 years showed an annual loss of 0.49 per cent from all causes. On the longleaf tract the loss on 350 trees worked for five years was 0.34 per cent per

annum. On another longleaf tract, which has been under observation by the experiment station, 1,308 trees (about 300 of which had been boxed previously) suffered a loss of 0.57 per cent per annum over a 4-year chipping period. The average annual loss from all causes on the 3,677 trees on all tracts under observation, worked four and five years, has been 0.74 per cent. This includes the exceptionally heavy loss following the flood in 1926 in slash pine timber and a considerable loss from windbreak in back-boxed trees on one of the areas. The average annual mortality over a long period of years for second-growth pines under conservative turpentining will probably come to about 0.5 per cent. It is very difficult to distinguish the primary cause of death, but in most cases it is considered that turpentining is the primary cause, an exception being the case of trees struck by lightning.

Lightning sometimes kills the trees. Out of 2,000 slash pine trees which have been under observation at Sampson Lake since 1923, 2 trees only, or 0.1 per cent, have been struck by lightning, and both were killed. Of the 350 longleaf trees on the Powell tract, none were killed by lightning during the period 1923–1927, and on another longleaf area where 1,308 trees have been under record for four years, 3 trees or 0.2 per cent have been struck by lightning and killed. This indicates that lightning is not a very important mortality factor in second-growth pine stands in the South.

SUMMARY AND CONCLUSIONS

In 1923 a number of experiments were started by the Southern Forest Experiment Station at Starke, Fla., for the purpose of determining the best naval-stores practice in second-growth slash and longleaf pines, the two species that are the main source of naval stores in the United States. Practice so determined should supply the definite information needed to avoid the severe damage to timber stands wrought by present and past turpentining methods and to combine profitable, sustained turpentining with timber conservation.

The principal studies were undertaken in dense second-growth 35-year-old slash pine and open 25-year-old second-growth longleaf pine.

The height-of-streak test, in which three heights, 0.32, 0.5 and 0.73 inch, were tried out, revealed the following advantages in favor of low chipping:

Low chipping produces fully as much gum in five years' time as higher working.

Low working permits the continuous chipping of one face on trees 11 or more inches in diameter for 10 to 12 years, whereas moderately chipped faces are worked out in 7 years and high-chipped faces in 5 years.

This additional working should furnish from 25 to 50 per cent more gum from each face.

The longer working period provides a longer healing period before back facing is begun and avoids the delay of a long rest period before back faces can be put on.

In naval-stores management the longer working period allows for sustained operation without interruption, yielding greater returns at lower operating costs.

Where timber is soon to be cut and only a short working period is permitted, low chipping reduces damage to the butt log nearly 50 per cent over that resulting from high chipping.

The low streak results in a smaller amount of damage from dry facing.

The depth-of-streak tests comprised four depths, 0.3, 0.5, 0.75, and 1 inch. The dense slash timber suffered a greater amount of damage than would have occurred in more open stands. The results obtained in this test revealed the following advantages in favor of shallow working:

Although different depths of streak produce no significant difference in total gum yield from 5 years' working, a greater reduction in yield from year to year accompanies the deeper work, indicating a considerably lower total yield for deep chipping if the work be extended to 7 or more years.

Eleven-inch or larger trees may be worked with shallow streaks for 7 years (or even longer with lower streaks) before the gum yields are reduced to an unprofitable point, as opposed to 5 years' work with deep chipping.

Mechanical weakening of the trees is avoided.

On shallow-chipped slash dry faces are only one-third as numerous as on deeply chipped slash pine.

Injury from insect and fungus attacks on dry faces is correspondingly lessened.

In the width-of-face tests, two series of face widths were used—in one case one-fourth, one-half, and three-fourths of the circumference, and in the other case one-fourth, one-third, and three-eighths.

Only 5 years' work is possible on the 75 per cent faces, because the extreme width of face precludes the possibility of back facing. Three sets of faces, covering a minimum of 15 years, are possible on the narrow-faced group without intermediate resting periods, and one set of back faces on medium-faced (50 per cent) trees. Total yields for wide, medium, and narrow faces may thus be estimated at 168.8, 262.5, and 372 barrels of turpentine per crop, respectively.

The second series of tests showed that the groups of faces that were one-third and three-eighths of circumference yielded, respectively, 8 and 9 per cent more than the narrow faces. However, three sets of faces may be cut in succession without interruption on the one-fourth circumference group, whereas some resting period may be required in the case of the wider faces before the trees can be worked with two sets of back faces.

A study of relative yields from front faces and back faces on slash pine showed that although first-year back-face yields may be lower than virgin front-face yields, nevertheless the back-face yields are likely to increase in subsequent years, whereas front faces generally register a decline in yield from year to year. The indications are that over five or more years of work back-face yields will underrun front-face yields by only a very small amount, if indeed they do not actually exceed them. These conclusions are drawn from yields obtained from working back faces on slow-growing trees following a short working of front faces, so that the trees were very little larger when back faced than when front faces were first worked. Where 8

or 10 years elapse between the placing of the front faces and the working of back faces in fast-growing timber the increase in diameter growth is sufficient to offset any decline in yield and give a substantial increase.

A study of density of stand as it affects gum yields and the ability of the trees to be turpentined without damage indicated that more open-growing trees yield considerably more than trees in dense stands and that there is less reduction in yield from year to year where the trees have plenty of space. A study of yield in relation to crown size indicated that more gum is obtained from the trees with larger crowns. Furthermore, on these large-crowned trees growing in the open there is less dry facing and faces heal more rapidly than in crowded stands.

A study of the effect of diameter size on naval-stores yield brought out the fact that yields increase with size of tree and that trees smaller than 9 inches can not be chipped with any assurance of obtaining a satisfactory profit unless the market prices are high or the trees considerably more vigorous than the average.

All chipping resulted in a reduction of diameter growth rate. This reduction increased with greater height of streak, greater depth of streak, and the use of two simultaneous faces as opposed to single faces.

Turpentining in fairly open longleaf stands apparently did not affect the ability of the trees to produce cones.

Dry facing is an important item in naval-stores management as it impairs the value of lumber and increases the likelihood of further degrade caused by insects and fungi. Dry facing is more serious in slash pine stands than in longleaf. It increases with density of stand and with greater depth of chipping and is normally more serious whenever any other destructive agencies have weakened the trees.

The principal insect associated with turpentining work is the turpentine borer (*Buprestis apricans*). Damage by this borer may be kept under control by the use of conservative methods, such as shallow chipping and the cutting of narrow faces. Tacking tins and avoiding the use of ax cuts in the face also reduce the likelihood of damage from these borers.

The whole series of tests show that timber may be chipped for a much longer time than under present commercial methods, with a higher sustained yield and less damage to the trees, provided low streaks, shallow streaks, and narrow faces are used. Also, if work is confined to trees above 9 inches in diameter, well spaced, and with plenty of crown, gum yields may be considerably increased. The results from all the stands under observation at Starke indicate that annual mortality in second-growth turpentine stands may be kept down to 0.5 per cent, provided conservative methods are employed.

A hypothetical example will illustrate in a very general way the prospective high yields and high returns to the timber owner where improved methods are employed, in contrast with the low returns from ordinary work.

Assuming a 70-acre stand of slash timber with 150 trees per acre averaging 9 inches d. b. h. at 27 years,[6] or a workable stand of

[6] Figures represent an average of the open stand at Sampson Lake.

approximately 10,000 trees, what may be expected from it as a reasonable maximum yield?

Many operators would cut two faces per tree, using streaks one-half inch high and one-half inch deep, and work the faces for five years. The indicated yield for one face per tree as shown in Figure 20, is about 40 barrels of turpentine per crop for 9-inch trees, but with two faces per tree the yield per face is reduced to about 75 per cent of this figure or 30 barrels. So double facing would yield 150 barrels per crop in five years' time. The whole tract would cup two crops yielding 300 barrels of turpentine. The trees would then be worked out at 32 years of age and should be cut. Presumably, they could be replaced in 27 or 28 years by a similar stand duplicating the yields at the age of 32 years or netting 600 barrels of turpentine in the 37 or 38 years since work was begun on this 70 acres.

In contrast with this procedure an improved method would include the following: One face per tree; face width equal to one-third of tree circumference; streaks one-half inch deep and one-fourth inch high; tins and cups raised yearly to a maximum height of 5 or 6 feet from the ground; back faces put on after one year's rest; three faces per tree in succession.

Such a tract would cup one crop, yielding an average of 36 barrels of turpentine annually for 12 years.[7] The 12-year yield would be 432 barrels. After a 1-year rest the trees would be 40 years old and at least 10½ inches in diameter, supposing that they grew 1 inch each 6½ years during turpentining. On trees of any given diameter, yields from back faces will be about 90 per cent of the yield from front faces. Accordingly, for the second 12-year chipping period the yields should be 90 per cent of 50 barrels or 45 barrels annually; that is, 540 barrels in 12 years' time. When these faces are worked out the trees will be 52 years old and nearly 12 inches d. b. h. A third crop of faces should then yield about 50 barrels yearly at a conservative estimate, or 600 barrels per crop for the 12 years. The trees will then be 65 years old and many of them 14 to 16 inches in diameter. They should then be cut.

The total yields for 38 years since the operation began in this manner would be 1,572 barrels of turpentine for the whole tract, as opposed to 600 barrels under the usual plan.

Under the more usual, short-time method of operation, at a leasing price of 15 cents a face for five years' time or $1,500 per crop, the revenue to the timber owner whose trees are worked by unimproved methods would amount to $2.37 per acre annually from five years' work on each of two sets of double faces for the 38 years from the time turpentining began up to the end of operations on the second stand.

On the other hand, when 36 years of work is possible on each tree during the 38-year period, the revenue at 3 cents per face per year would be $4.26 per acre yearly for the 38 years after the stand has reached workable size. This is a net gain of $1.89 per acre per year derived from the use of improved methods. The naval-stores revenue has been increased by 80 per cent.

[7] This is 90 per cent of the average annual yield for the first 5 years, as shown on the curve in Figure 20. Since there is a gradual reduction in yield each year, the yield for 12 years would not average so high as for the first 5 years.

In addition to this increased naval-stores revenue, the use of improved turpentine practices will also indirectly bring in more revenue from stumpage, because the trees are larger and have a greater value for higher priced commodities.

Turpentining is not inconsistent with forest conservation when properly done, nor are high yields inconsistent with conservative chipping methods. Light working is to the interest of both the timber owner and the naval-stores operator.

APPENDIX

COMPARISON OF TREE GROUPS USED IN STUDIES

Tables 21 to 24 give particulars of the tree groups used in the various tests, based on 1923 average-tree measurements.

TABLE 21.—*Comparative measurements of tree groups used in height-of-streak tests*

SLASH PINE

Height of streak	Diameter at—		Height	Crown		Rings in last 0.5-inch growth	Age
	4½ feet	9 feet		Width	Length		
Inch	*Inches*	*Inches*	*Feet*	*Feet*	*Feet*	*Number*	*Years*
0.32	10.88	--------	71.6	14.5	--------	5.3	35
.50	10.72	9.78	73.4	15.8	--------	5.4	35
.73	10.79	10.00	70.7	11.3	--------	5.4	35

LONGLEAF PINE

0.32	9.73	9.23	55.50	17.68	31.10	5.56	36
.50	9.70	8.92	47.59	20.84	32.24	3.00	27
.73	9.35	8.94	48.22	22.16	31.54	4.14	28

TABLE 22.—*Comparative measurements of tree groups used in depth-of-chipping tests*

SLASH PINE

Depth of streak	Diameter at —		Height	Crown		Rings in last 0.5-inch growth	Age
	4½ feet	9 feet		Width	Length		
Inch	*Inches*	*Inches*	*Feet*	*Feet*	*Feet*	*Number*	*Years*
0.30	10.83	10.0	70.14	10.4	15.1	5.28	35
.50	10.72	9.8	73.39	15.8	--------	5.42	35
.75	10.75	10.0	73.22	12.6	15.6	5.56	35
1.00	10.81	10.1	71.34	14.0	16.8	5.66	35

LONGLEAF PINE

0.30	9.99	9.38	47.69	27.7	32.5	2.78	22.0
.50	9.70	8.92	47.59	20.8	32.2	3.00	27.5
.75	9.62	--------	50.75	23.0	32.8	3.06	24.5
1.00	9.56	9.13	53.67	21.4	31.8	3.22	26.0

TABLE 23.—*Comparative measurements of tree groups used in width-of-face tests, slash pine*

SERIES 1

Width of face (circumference)	Diameter at —		Height	Crown		Rings in last 0.5-inch growth	Age
	4½ feet	9 feet		Width	Length		
Per cent	*Inches*	*Inches*	*Feet*	*Feet*	*Feet*	*Number*	*Years*
25	8.2	7.6	----------	12.6	20.4	5.4	33
50	8.4	7.7	----------	9.8	18.3	5.8	33
75	8.5	7.8	----------	12.2	19.5	5.2	33

SERIES 2

25	10.4	9.7	76.0	18.3	24.0	5.56	35
33⅓	10.7	9.8	73.4	15.8	----------	5.42	35
37½	10.4	9.7	72.1	17.2	22.7	6.24	35

TABLE 24.—*Comparative measurements of tree groups used in density-of-stand tests*

SLASH PINE

Stand density	Trees per acre	Diameter at—		Height	Crown		Rings in last 0.5-inch growth	Age
		4½ feet	9 feet		Width	Length		
	Number	*Inches*	*Inches*	*Feet*	*Feet*	*Feet*	*Number*	*Years*
Dense A	170	10.7	9.8	73.4	15.8	20.5	5.4	35
Dense B	260	10.5	9.8	73.1	12.8	15.5	6.1	35
Open	[1] 75	10.7	9.6	----------	24.0	28.9	4.6	26

LONGLEAF PINE

Dense	135	9.4	----------	56.1	18.2	28.8	3.8	26
Open	100	9.7	8.9	47.6	20.8	32.2	3.0	27

[1] Estimated.

GLOSSARY OF FORESTRY AND NAVAL-STORES TERMS [8]

Advance streak.—One or more streaks cut in advance of the regular chipping season for the purpose of stimulating oleoresin production.

Apron.—A flat metal strip attached or inserted in a horizontal plane in a tree immediately above the cup to direct the oleoresin from the face into the cup.

Back face.—A face placed on a tree already turpentined on one or more faces; usually a second face placed on the side of the tree opposite the first or front face.

Bark bar.—The vertical strip of unchipped bark between two faces.

Barrel.—Turpentine barrels hold 50 gallons. A barrel of rosin, known as a round barrel, weighs about 500 pounds gross or 420 pounds net. Market quotations for a barrel of rosin are based upon a theoretical barrel of 280 pounds gross weight.

Blue stain.—A blue-gray discoloration of sapwood caused by minute vegetable organisms; often called sap stain.

Breast height.—Four and one-half feet above the ground.

Box.—A cavity cut in the base of a tree to collect the oleoresin produced when the tree is chipped. Cups are now almost universally used in place of boxes.

[8] Sources consulted: *11, 38.*

Chip.—(Noun) The wood removed by chipping. (Verb) To cut a streak or wound a tree for the purpose of allowing the oleoresin to flow.

Chip paddle.—A board or canvas screen placed against the tree during chipping to shield the cup from bits of wood or bark.

Close cupping.—Overworking a tree by cutting too many faces.

Crop.—(1) Ten thousand turpentine faces. (2) The total yearly production of naval stores for the entire industry.

Crown.—The portion of a tree composed of live limbs and foliage.

Crown class.—A classification of trees according to the proportionate amount of direct sunlight which the crown receives. The most commonly recognized classes are dominant, codominant, intermediate, and suppressed.

Dominant.—Trees having the crown free to light on all sides because of greater height.

Codominant.—Trees having the crown free to top light and some side light; trees somewhat shorter than dominant.

Intermediate.—Trees having the crown shaded on the sides but free to light at the top.

Suppressed.—Trees having the crown entirely overtopped and shaded.

Crown diameter.—The average maximum width or spread of the tree crown.

Crown length.—The distance from the base of the lowest live limb to the highest point of the crown.

Cup.—(Noun) A receptacle of earthenware, galvanized iron, aluminum, or other materials, made in various shapes, used for catching the flow of oleoresin resulting from chipping. (Verb) To work for turpentine.

D. b. h.—Diameter at breast height (4½ feet).

Depth of streak.—*See* Streak depth.

Dip.—(Noun) The oleoresin which collects in the cups as distinct from the scrape, or that which hardens on the face. (Verb) To gather the oleoresin from the cups and collect it in barrels to be taken to the still.

Dry face.—A face on which the secretion of resin has stopped over all or a part of the streak, as the result of interference with the normal flow of sap behind the face.

Face.—(Noun) The total scarred surface of a turpentined tree formed by the cutting of successive streaks. (Verb) To slab off the bark and occasionally wood in preparation for setting the aprons or gutters.

Face height.—The measure of the vertical distance between the bottom of the first streak and the top of the last streak, measured along the shoulder or edge of the face.

Face width.—The measure of the horizontal distance between two edges or shoulders of a face, measured in these studies by a flexible tape across the face surface.

Flatwoods.—The poorly drained level portion of the southern coastal plain on which grow forests of slash and longleaf pines.

Gum.—Synonymous with oleoresin or resin.

Gutter.—A V-shaped metal strip or trough inserted or attached obliquely immediately above the cup to direct the oleoresin into the container.

Gutter chisel.—A wedge-shaped tool (used with a maul) for making a slit in the wood of a tree for the insertion of gutters or aprons. (Fig. 23, 2.)

Hack.—A cutting tool used in chipping trees to induce the production of oleoresin. The cutting edge of the American hack is a sort of half-round or U-shaped gouge, set on a wooden stock which is weighted at the end. Several sizes are made, based on the width of the U. No. 0 is seven-eighths inch wide, No. 1 is 1 inch wide, No. 1½ is 1⅛ inches, and No. 2 is 1¼ inches. (Fig. 23, 5.)

Height of streak.—*See* Streak height.

Height of face.—*See* Face height.

Herty cup.—An earthenware container shaped like a flower pot.

Increment boring.—A cylindrical core extracted from a tree by means of a hollow auger for the purpose of determining age or growth rate of the tree by observing the annual rings of growth.

Jump streak.—A streak cut in new wood a short distance above the peak of the face in such a way that a narrow strip of uncut wood is left between the new or jump streak and the old face.

Naval stores.—Originally all material used in the construction of wooden vessels, including timber, lumber, masts, yards, flax, tar, pitch, rosin, and cordage. Now used to denote turpentine, rosin, pitch, tar, and other chemical products extracted from oleoresin.

Oleoresin.—An oily resin or gum extracted from many species of pines as distinct from the watery sap. This oleoresin is produced by living cells surrounding the resin canals or ducts.

Operator.—A producer of naval stores. An operator, besides working trees, usually extracts and distills the oleoresin.

Peak.—The sharp projecting point of wood at the middle of the top of a face formed by two streaks sloping downward toward each other.

Pull.—(1) To cut a streak on a high face by means of a puller (fig. 23, 6) or chipping tool mounted on a long handle and pulled through the wood by the chipper; (2) to extract or remove aprons or gutters by means of long-handled forceps called gutter pullers.

Raise cups.—To change the cups from a lower position to a point close to the top of a face in order to lessen evaporation from gum running over a long face .

Resin.—Synonymous with oleoresin, or gum.

Ring.—The annual layer or ring of wood produced by the tree in a season.

Rosin.—That portion of the crude oleoresin, freed from trash and water, which remains after volatilization of the turpentine by distillation.

Round tree.—A tree in which no turpentine face has yet been cut.

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FIGURE 23.—Turpentine tools: 1, Broadax; 2, gutter chisel, pringle; 3, maul; 4, hogal; 5, hack; 6, puller; 7, push-down scraper; 8, pull-down scraper; 9, gutter puller; 10, dip iron

Scrape.—Hardened oleoresin which forms on a face, as distinct from that which runs down into the cup to form dip.

Shoulder.—The outside edge of a face where the streak first cuts into the wood.

Site index.—A figure which represents the tree-growing quality of land as expressed by the height in feet of the average dominant trees at 50 years.

Spirits.—*See* Turpentine.

Streak.—A wound formed when a tree is chipped. In American chipping, this consists of two downward cuts meeting in a V. The angle at which the tool is tilted in the chipper's hands determines whether a shade streak, square streak, or sun streak is cut. (Fig. 5.) A streak cut with a French chipping tool is formed by removing a thin slab of bark and wood, shaped like an inverted U.

Streak depth.—The horizontal measure of a streak taken radially from the inside of the bark at the deepest point.

Streak height.—The vertical measure of a streak taken along the grain.

Streak width.—Streak height.

Tin.—A comprehensive term synonymous with apron or gutter. Any type of metal strip used to guide oleoresin from the face into the cup.

Turpentine.—The volatile oil, often called spirits, which is one of the main constituents of oleoresin derived in the process of distillation. A complex chemical substance composed primarily of terpenes, expressed by the general formula $C_{10}H_{16}$.

Turpentining.—The process of working a tree to obtain oleoresin from its gum; as commonly used, the term may also include the distilling process.

Virgin faces.—Faces during the first year of chipping.

Width of face.—*See* Face width.

Width of streak.—*See* Streak height.

LITERATURE CITED

(1) ASHE, W. W.
1894. FORESTS, FOREST LANDS, AND FOREST PRODUCTS OF EASTERN NORTH CAROLINA. N. C. Geol. Survey Bul. 5, 128 p., illus.

(2) BUFFAULT, M. P.
1926. LE PIN MARITIME DANS LE SUD-OUEST DE LA FRANCE. Actes Cong. Internatl. Sylviculture 4: 241–270.

(3) BULLARD, E. R.
1926. [LETTER IN ANSWER TO THE QUESTION: WHAT CAUSES DRY FACING ON PINES THAT ARE BEING WORKED FOR NAVAL STORES?] Naval Stores Rev. and Jour. Trade 36 (15): 16–17.

(4) BURKE, H. E.
1910. INJURIES TO FOREST TREES BY FLAT-HEADED BORERS. U. S. Dept. Agr. Yearbook 1909: 399–415, illus.

(5) CARR, A. S.
1926. [LETTER IN ANSWER TO THE QUESTION: WHAT CAUSES DRY FACING ON PINES THAT ARE BEING WORKED FOR NAVAL STORES?] Naval Stores Rev. and Jour. Trade 36 (15): 16.

(6) CARY, A.
1923–28. STUDIES ON FLOW OF GUM IN RELATION TO PROFIT IN THE NAVAL STORES INDUSTRY. Naval Stores Rev. and Jour. Trade 33 (38): 20–20A; (40): 20–20A; (44): 6, 9; 34 (4): 10; (5): 10, 15, 19; (8): 10, 16; 35 (20): 6–7; (21): 6, 18; (22): 6–7, 18; (23): 6–7, 9, 19; (25): 9, 18; 36 (51): 8–10; 38 (25): 14–15; (26): 14–15; (27): A–G [not paged with rest of number], illus.

(7) COSCULLUELA, P.
1926. TRATAMIENTO DEL PINUS PINASTER (SOL) PARA OBTENER RESINAS EN LOS TERRENOS ARRENOS DE LA CUENCA DEL DUERO. Actes Cong. Internatl. Sylviculture 3: 681–685, illus.

(8) CRAIGHEAD, F. C.
1927. THE TURPENTINE BORER ON THE FLORIDA NATIONAL FOREST. U. S. Dept. Agr. Forest Worker 3 (4): 11–12.

(9) ——— and MIDDLETON, W.
1930. AN ANNOTATED LIST OF THE IMPORTANT NORTH AMERICAN FOREST INSECTS. U. S. Dept. Agr. Misc. Pub. 74, 30 p.

(10) ELDREDGE, I. F.
1914. THE ADMINISTRATION OF A NATIONAL FOREST FOR NAVAL STORES. Soc. Amer. Foresters Proc. 9: 310–326.

(11) GAMBLE, T.
1928. NAVAL STORES YEARBOOK FOR 1928–29. 100 p., illus. Savannah, Ga.

(12) GERRY, E.
1921. THE PRODUCTION OF CRUDE "GUM" BY THE PINE TREE. *In* Gamble, T., Naval Stores, 1921, p. 147–153.

(13) ———
1922. OLEORESIN PRODUCTION: A MICROSCOPIC STUDY OF THE EFFECTS PRODUCED ON THE WOODY TISSUES OF SOUTHERN PINES BY DIFFERENT METHODS OF TURPENTINING. U. S. Dept. Agr. Bul. 1064, 46 p., illus.

(14) ———
1923. THE GOOSE AND THE GOLDEN EGGS OR NAVAL STORES PRODUCTION À LA AESOP. South. Lumberman 1456: 36–38, illus.

(15) ———
1925. EFFECT OF HEIGHT OF CHIPPING ON OLEORESIN PRODUCTION. Jour. Agr. Research 30: 81–93, illus.

(16) GILLICAN, C. C.
1926. [CUPPING TIMBER LOW IN VITALITY CAUSES DRY FACING.] [Letter to Naval Stores Review.] Naval Stores Rev. and Jour. Trade 36 (16) : 22.
(17) HARPER, V. L.
1928. SMALL TREES MAKE MORE SCRAPE THAN BIG TREES. Naval Stores Rev. and Jour. Trade 38 (3) : 9.
(18) HERTY, C. H.
1903. A NEW METHOD OF TURPENTINE ORCHARDING. U. S. Dept. Agr., Bur. Forestry Bul. 40, 43 p., illus.
(19) ———
1911. RELATION OF LIGHT CHIPPING TO THE COMMERCIAL YIELD OF NAVAL STORES. U. S. Dept. Agr., Forest Serv. Bul. 90, 36 p., illus.
(20) HODGES, C. S.
1926. [LETTER IN ANSWER TO THE QUESTION: WHAT CAUSES DRY FACING ON PINES THAT ARE BEING WORKED FOR NAVAL STORES?] Naval Stores Rev. and Jour. Trade 36 (15) : 16.
(21) HOLLAND, J. H.
1926. FOUR MAJOR CAUSES GIVEN FOR DRY-FACING IN PINES. [Letter to Weekly Naval Stores Review, quoting opinions of L. L. Adams and E. W. Minton.] Naval Stores Rev. and Jour. Trade 36 (17: 6.
(22) KIENITZ, M.
1924. WEITERE ENTWICKLUNG DER HARZNUTZUNG AN DER GEMEINEN KIEFER, PINUS SILVESTRIS L. Ztschr. Forst u. Jagdw. 56: 399–429.
(23) LEBEDYEV, V. I.
1929. BLUE STAIN AND THE TURPENTINE INDUSTRY. Contrib. Inst. Indus. Research 5. Archangel, U. S. S. R. [Title translated from Russian.]
(24) MCARTHUR, W. E.
1926. [LETTER IN ANSWER TO THE QUESTION: WHAT CAUSES DRY FACING ON PINES THAT ARE BEING WORKED FOR NAVAL STORES?] Naval Stores Rev. and Jour. Trade 36 (15) : 17.
(25) MCDOUGALD, W. E.
1929. THE PRODUCER OF GUM SPIRITS TURPENTINE AND GUM ROSINS IN THE SOUTH. Naval Stores Rev. and Jour. Trade 39 (30) : 16–17.
(26) MCKEE, E. R.
1924. THE FRENCH TURPENTINING SYSTEM APPLIED TO LONGLEAF PINE. U. S. Dept. Agr. Circ. 327, 16 p., illus.
(27) MARTIN D. F.
1926. [LETTER IN ANSWER TO THE QUESTION: WHAT CAUSES DRY FACING ON PINES THAT ARE BEING WORKED FOR NAVAL STORES?] Naval Stores Rev. and Jour. Trade 36 (15) : 17.
(28) MILLS, E. B.
1926. [DROUGHT, DEEP CHIPPING, AND PINE BEETLES CAUSE DRY FACES.] [Letter to Naval Stores Review in answer to the question: Why dry faces on turpentine trees?] Naval Stores Rev. and Jour. Trade 36 (17) : 6.
(29) MIROV, T. N.
1930. TURPENTINING EXPERIMENTS WITH WESTERN YELLOW PINE IN NORTHERN CALIFORNIA. Jour. Forestry 28 : 521–532, illus.
(30) MITCHELL, A. J., and ENSIGN, M. R.
1928. THE CLIMATE OF FLORIDA. Fla. Agr. Expt. Sta. Bul. 200, p. [95]–[300], illus.
(31) PLANKE.
1922. SAMENERZEUGUNG GEHARZTER FOHREN. Forstwiss. Centbl. 66 : 172–175.
(32) ST. GEORGE, R. A.
1925. THE RECENT DEATH OF LARGE QUANTITIES OF SOUTHERN PINE. Amer. Lumberman 2607: 50–51, illus.
(33) ——— and BEAL, J. A.
1929. THE SOUTHERN PINE BEETLE: A SERIOUS ENEMY OF PINES IN THE SOUTH. U. S. Dept. Agr. Farmers' Bul. 1586, 18 p., illus.
(34) SCHWERDTFEGER, F.
1929. ZUWACHSMEHRUNG DURCH HARZUNG. Ztschr. Forst u. Jagdw. 61: 485–495, illus.

(35) SELLARS, J. D.
1926. [LETTER IN ANSWER TO THE QUESTION: WHAT CAUSES DRY FACING ON PINES THAT ARE BEING WORKED FOR NAVAL STORES?] Naval Stores Rev. and Jour. Trade 36 (15): 16.

(36) SMITH, C. S.
1914. TURPENTINE POSSIBILITIES ON THE PACIFIC COAST. Soc. Amer. Foresters Proc. 9: 327–341, illus.

(37) TURNER, E. R.
1926. [MORE POINTS ON CAUSES OF DRY FACES IN TREES WORKED FOR TURPENTINE.] [Letter to Editor, Naval Stores Review.] Naval Stores Rev. and Jour. Trade 36 (20): 10.

(38) UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE.
1905. TERMS USED IN FORESTRY AND LOGGING. U. S. Dept. Agr., Bur. Forestry Bul. 61, 53 p., illus.

(39) ———
1929. VOLUME, YIELD, AND STAND TABLES FOR SECOND-GROWTH SOUTHERN PINES. U. S. Dept. Agr. Misc. Pub. 50, 202 p.

(40) VINING, L. D.
1928. DAMAGE RESULTING FROM RECENT FLORIDA HURRICANE TO SECOND-GROWTH TURPENTINE TIMBER. Naval Stores Rev. and Jour. Trade 38 (37): 14, illus.

(41) WEIDEMAN.
1929. DER EINFLUSS DER HARZNUTZUNG AUF DEN ZUWACHS DER KIEFER. Forstl. Wchnschr. Silva 17: 137–139.

(42) WYMAN, L.
1928. MORE GUM FROM FAST GROWING PINES. U. S. Dept. Agr. Forest Worker 4 (3): 9.

ADDITIONAL LITERATURE

ANONYMOUS.
1855. TURPENTINE PRODUCTION OF THE SOUTH. DeBow's Rev. 18 (n. s.) 1: 61–63.

BARRAUD, M.
1930. L'ETUDE DES GEMMES. Bul. Inst. Pin (Ser. 2) 10: 217–224.

BETTS, H. S.
1912. POSSIBILITIES OF WESTERN PINES AS A SOURCE OF NAVAL STORES. U. S. Dept. Agr., Forest Serv. Bul. 116, 23 p., illus.

BUYS, C. B., JAPING, C., and FERNANDES, D.
1928. BIJDRAGE TOT DE KENNIS VAN PINUS MERKUSII JUNGH ET DE VR., MEER IN HET BIJZONDER IN DE GAJO-LANDEN. Dept. Landb., Nijh. en Handel [Dutch East Indies] Meded. Proefsta. Boschw. 19, 139 p., illus.

CARY, A.
1929. GOOD NAVAL STORES PRACTICE—BASED ON STUDIES OF THE FOREST SERVICE AND THE EXPERIENCE OF SUCCESSFUL OPERATORS. U. S. Dept. Agr. Leaflet 41, 4 p., illus.

DEBOW, J. D. B.
1851. PRODUCTION OF TURPENTINE AT THE SOUTH. DeBow's South. and West. Rev. (o. s.) 11: 303–305.

———
1856. TURPENTINE IN THE SOUTH. South. States 3: 350–355.

ELORRIETA, O.
1926. LA ORDENACION DE LOS PINARES DÉSTINADOS A LA EXPLOTACION RESINERA EN LA ZONA MEDITERRANEA. Actes Cong. Internatl. Sylviculture 4: 348–369.

GERRY, E.
1931. IMPROVEMENT IN THE PRODUCTION OF OLEORESIN THROUGH LOWER CHIPPING. U. S. Dept. Agr. Tech. Bul. 262, 24 p., illus.

LUNDBERG, G.
1917. TYSKLANDS NUVARANDE HARTSINDUSTRI. Skogsvårdsför. Tidskr. Arg. 15: 735–762, illus.

OUDIN, BIQUET, and SALVAT.
1926. PREMIÈRES ÉTUDES SUR LE GEMMAGE DES PINS EN FRANCE. Actes Cong. Internatl. Sylviculture 3: 648–675, illus.

SCHIERLINGER, L.
1919. HARZNUTZUNG DER FÖHRE. Naturw. Ztschr. Forst u. Landw. 17: 281–365, illus.

SCHORGER, A. W., and BETTS, H. S.
1915. THE NAVAL STORES INDUSTRY. U. S. Dept. Agr. Bul. 229, 58 p., illus.
——— and PETTIGREW, R. L.
1917. INCREASED YIELD OF TURPENTINE AND ROSIN FROM DOUBLE CHIPPING. U. S. Dept. Agr. Bul. 567, 9 p., illus.
SEVILLA, M., and TAMEO, M.
1928. SERVICO FORESTAL DE INVESTIGACIONES Y EXPERIENCIAS INSTITUTO NACIONAL DE INVESTIGACIONES Y EXPERIENCIAS. Agron. y Forest, Ano 1: 105–115.
WYMAN, L.
1924. HOW FAST SHOULD A FACE BE RAISED IN CHIPPING TIMBER? South. Lumber Jour. 50 (20): 17–18, illus.
———
1924. HOW DEEP SHOULD I CHIP MY TIMBER? South. Lumber Jour. 50 (24): 20.
———
1926. PRELIMINARY NAVAL STORES YIELD TABLES. Naval Stores Rev. and Jour. Trade, v. 36, no. 33, [4] p., illus. [Not paged.]
———
1927. TURPENTINE PINE CHIPPING TO GET HIGHEST YIELDS. U. S. Dept. Agr. Yearbook 1926: 738–741, illus.
———
1928. GUM YIELDS OF PINES INCREASE FAST WITH DIAMETER INCREASE. U. S. Dept. Agr. Yearbook 1927: 355–356.
———
1928. NAVAL STORES YIELD MUCH AFFECTED BY METHODS OF CHIPPING. U. S. Dept. Agr. Yearbook 1927: 473–475.
———
1929. FLORIDA NAVAL STORES. Fla. Dept. Agr. Bul. 25 (n. s.), 42 p., illus.
ZIOPKALO, W., and RUDNEW, D.
1929. ON THE QUESTION OF THE EFFECT OF TURPENTINING ON INCREASING DAMAGE. Lesowod. 6. [Title translated from German review of original Russian publication.] Review in Forstarchiv., p. 58.

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FACTORS AFFECTING THE PRICE OF RICE

BY

CARLOS E. CAMPBELL

Associate Agricultural Economist, Division of Statistical and Historical Research, Bureau of Agricultural Economics

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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DEVELOPMENT OF THE RICE-GROWING INDUSTRY

Rice growing was an important part of Colonial agriculture as early as 1700. The surplus production during the Colonial period was a significant part of the exports of South Carolina. Both production and export trade increased steadily for more than a century and a half. At the beginning of the War between the States production dropped to almost nothing and, in spite of the relatively high level of prices, did not regain pre-war proportions until 1880. It was not until 1914 that production caught up with domestic consumption and exportation was again resumed.

Prior to 1860 rice was grown mainly in South Carolina and Georgia. Prices were favorable for expansion in production, but because of the crop's peculiar physical requirements of soil and climate, production was restricted to certain sections of those States. The Civil War resulted in disaster for the South Carolina rice-growing industry. The very slow recovery of that industry, together with the relatively high level of prices prevailing after the war, stimulated experimentation in rice growing in other sections of the South. Improvement in cultural practices and the introduction of machine

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methods of harvesting were also responsible for increases in acreage and production after 1884. But it was not until after the discovery that rice could be grown successfully on a commercial scale in Louisiana, Texas, and Arkansas that the United States production began to increase rapidly.

Production in the Southern States has been increasing at a much lower rate since 1920 than during the period 1900 to 1920. Favorable prices stimulated production from 1900 to 1905; from 1905 to 1910 prices were declining, but production continued to increase except for a temporary setback in 1905 and 1906. Better prices beginning with 1911 stimulated the rate of increase in production, so that by 1914 the Southern States alone were producing enough to satisfy the demand of the United States. Had normal conditions prevailed from 1914 to 1920, and if the rate of increase in production which obtained from 1900 to 1914 had been continued, it is probable that production would have been fairly well adjusted to demand. Normal conditions, however, did not prevail during this period, war prices caused the rate of increase in production to rise again, resulting in a 44,000,000-bushel crop in 1920–21. The subsequent low prices caused relatively low production for the next five years, but the higher prices of 1924 and 1925 again stimulated production during the following three years.

The southern rice belt of the United States is producing between 30,000,000 and 35,000,000 bushels of rough rice annually. Approximately three-fourths of this production is consumed by the United States and its possessions, the other one-fourth being sold in foreign markets.

ACREAGE CHANGES AS AFFECTED BY FARM PRICES

Rice farmers react to price in the same general way in which all producers react to the prices of their commodities; that is, following a year of relatively high prices there will be a tendency toward an increase in acreage, while a year of relatively low prices precedes a certain decrease in acreage. There are, however, certain peculiarities of change in rice acreage, as affected by price, that require explanation.

Growing rice under irrigation—and a very large percentage of it is grown by that method—requires a large amount of capital in addition to land and labor. Before rice can be grown profitably on most of the rice land, wells must be dug, canals built, or some other source of water provided, and expensive pumping machinery installed. As nearly as is practicable, the watering equipment is adjusted to the farm acreage so that the optimum watering capacity of the equipment can be used each year. That is, a farm on which 160 acres of land were prepared for rice growing probably would have a plant capable of supplying water to 120 acres.[2]

Generally speaking, the rice farm is not a very elastic unit in so far as rice acreage is concerned. If a farmer having the above-mentioned farm and equipment wants to expand his rice acreage for a certain year following a year of favorable prices, he finds that 120 acres is his limit unless he increases his watering equipment or can rent water. In some sections the latter course is possible and results in some

[2] It is a practice in many rice sections to grow rice on only two-thirds or three-fourths of the land each year, the remainder being dry-farmed or fallowed for control of red rice.

expansion of acreage. In the former case, however, there is likely to be no expansion if he grew 120 acres the previous year. One year's favorable prices are usually not sufficient stimuli to induce a farmer to add to his watering equipment. There is some opportunity to expand the entire rice section because not all farmers having units of this size will have been growing rice on three-fourths of the land. Some farmers will grow rice on two-thirds of their rice land, allowing one-third to lie fallow. In such a case the acreage could be expanded from two-thirds to three-fourths without increasing the watering equipment.

On the other hand an unfavorable price may not result in a great reduction the following year because a material decrease in acreage would mean operating only a part of the watering plant or operating all of it only part of the time. In either case the watering cost for the farm as a whole would not be reduced in the same proportion as the acreage of rice, and quite likely the acre cost of the crop would be greater.

Therefore, within the close limits of elasticity of acreage on most rice farms, prices can be expected to effect the usual changes; high prices will be followed by increases in acreage the next year, and low prices will be followed by decreases in acreage.

As has been shown, acreage can be expanded by keeping land in rice an extra year and thus postponing the time when it should be dry-farmed or fallowed. But if this is done this acreage can be maintained the next year only at the expense of quality. That explains in part why two successive years of high prices usually result in an actual decrease in acreage as compared with the acreage of the first year following high prices. There is, however, another effect of two successive years' high prices; under this stimulus some farmers will begin preparing new land for rice, and if the next year should bring favorable prices (three successive years of high prices) new watering equipment is likely to be installed and acreage thus increased as a result of the third year of high prices. In fact, this last increase is likely to be greater than the past prices justify. The reason for adding pumping equipment and thus increasing acreage is that the farmers interpret three successive years of high prices as an upward trend in demand which justifies permanent increases in production. Watering equipment can not economically be added in small units; therefore the farmer increases his production unit to take care of anticipated future demands rather than merely the demand evidenced by the past three years' prices. Experience has shown that the increase in acreage the third year is too great and the resulting production is too large, causing prices to fall. During the next three years falling prices are experienced because of overproduction.[3]

This completes the 6-year cycle—three years up and three down. (Fig. 1.)

Because so much depends upon the way in which farmers interpret prices, it can not be said just how long this rice cycle will continue. Since there is a relatively small number of rice farmers in the United States as compared with total rice acreage, a change of policy on

[3] It is recognized that not all farmers would follow this reasoning and react together. There is, however, a tendency for credit organizations loaning capital to rice farmers to extend credit for purchase of equipment and encourage increases in acreage only after prices have continued to rise for two or three years.

the part of a comparatively few farmers might cause the cycle to change or even to disappear.

Results of the study of effect of prices on acreage changes confirm the above reasoning. Prices of rice for three previous years influence the rice acreage for any given year. The most important of these three factors is price one year previously, the next factor of importance is price in the third previous year, and price in the second previous year had the least influence of the three. It should also be noted that prices one year and three years previously have a positive effect on acreage changes, whereas price in the second previous year is usually associated with an opposite change in acreage. This apparent negative relationship between price two years ago and change in acreage is due to certain farm-management practices inherent in rice farming.

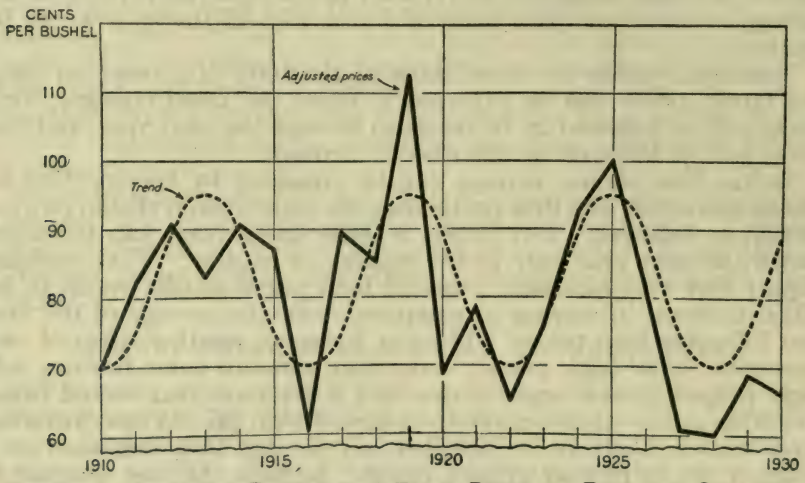

FIGURE 1.—ADJUSTED DECEMBER 1 FARM PRICE OF RICE AND CYCLICAL TREND, UNITED STATES, 1910–1930

There has been a tendency for December 1 farm prices to follow a cyclical trend. There is, however, no assurance that this trend will continue.

The reason for the influence of the most important of these factors, price one year previously, is that the farmer anticipates similar prices the next year and adjusts his acreage to take advantage of the anticipated price. An inspection of Figure 1 will serve to show that price very rarely remains the same two years in succession; in fact, it tends to follow a fairly definite cyclical trend, rising three years and falling three years.

DEMAND FOR SOUTHERN-TYPE RICE

A large part of the southern-grown rice is consumed in the United States and its possessions. Prior to 1860 the domestic demand was less than the production; from 1860 to 1914 the United States demand was too great for local production and imports of foreign rice were necessary to satisfy it. Since 1914 production has exceeded domestic consumption and each year has left an exportable surplus; therefore foreign demand has again become vitally important to the rice industry in the United States.

An analysis of domestic demand for rice shows that within continental United States the annual consumption of rice does not vary a great deal with changes in price. Total consumption within the United States has gradually increased during the last 15 years, but per capita consumption during the same period has shown little change. This small influence of price on consumption may partially be accounted for by the fact that during the period studied nominal wages advanced more rapidly than retail rice prices. Thus, apparently, an advance in real wages also affects consumption and tends to modify the statement of effect of price on consumption.

The conclusions regarding the effect of wages on consumption were based upon the assumption that the consumption of rice within the groups depending upon wages for the major part of their incomes, was greater than that within nonlaboring groups. This assumption appears to be substantiated by a limited study of consumption of various foods within a certain labor group.[4]

This study shows that the rice consumption by the laborer himself, as well as the per capita consumption by his family, was much greater than the per capita consumption for the United States as a whole. Another significant fact revealed by this study was that the per capita consumption of rice in the Southern States was much greater than that in the Northern States. Different food habits probably are responsible for the greater part of the difference between per capita consumption in the two sections.

Competition of other foods with rice to satisfy the demand for carbohydrates might be expected to reduce the consumption of rice when such other foods were relatively low in price. An increase in the supply of sweet potatoes and corn meal appears to have affected only slightly the consumption of rice in the South, while for the United States as a whole the effect was so small that it was practically negligible.

An increase in demand may occur as a result of increases in population with no change in per capita consumption, or by per capita consumption increasing while price and population remain the same, or by a combination of both. The most dependable of these factors is increase in population, which accounts for an average annual increase of approximately 10,000,000 pounds of cleaned rice in the demand in continental United States.

Porto Rico and Hawaii are important markets for the rice crops of continental United States. The population of these possessions consumes much more rice per capita than does the population of continental United States. The per capita consumption in Porto Rico in 1929–30 amounted to 125.7 pounds, in Hawaii 229.4 pounds, and in continental United States only 5.3 pounds. (Fig. 2.) The total consumption of these island possessions is about 40 per cent of the amount consumed in continental United States.

Porto Rico is a very important market for the southern rice. Although price variations have a more pronounced effect on consumption there than in the United States, that effect still does not cause great variations in consumption. The demand for rice in Porto Rico is increasing not only because of the growth in population but also

[4] UNITED STATES DEPARTMENT OF LABOR, BUREAU OF LABOR STATISTICS. CONSUMPTION OF FOOD IN SHIPBUILDING DISTRICTS. U. S. Dept. Labor, Mo. Labor Rev. 7 (6): 115–146. 1918. [See also vols. 6 and 8, and v. 7, nos. 2, 3, and 4. Data are included in U. S. Dept. Labor, Bur. Labor Statistics Bul. 357, Cost of Living in the United States, 1924.]

because of the increase in per capita consumption. The net effect of growth in population and increase in per capita consumption in the last 10 years has been to increase the annual average consumption by about 7,000,000 pounds.

Thus we find that the demand for rice in both continental United States and Porto Rico is relatively inelastic; that is to say, price increases or decreases within fairly wide limits have little effect upon the amount of rice consumed within the United States and its possessions. The most important factor affecting an increase in domestic consumption is increase in population. It can be assumed, therefore, that this relatively small annual increase of the last 10 years probably will continue for the next few years.

Foreign demand for southern-type rice is more elastic than the domestic demand, but the quantity exported has not been sufficiently large during the last 10 years to provide a good measure of this elas-

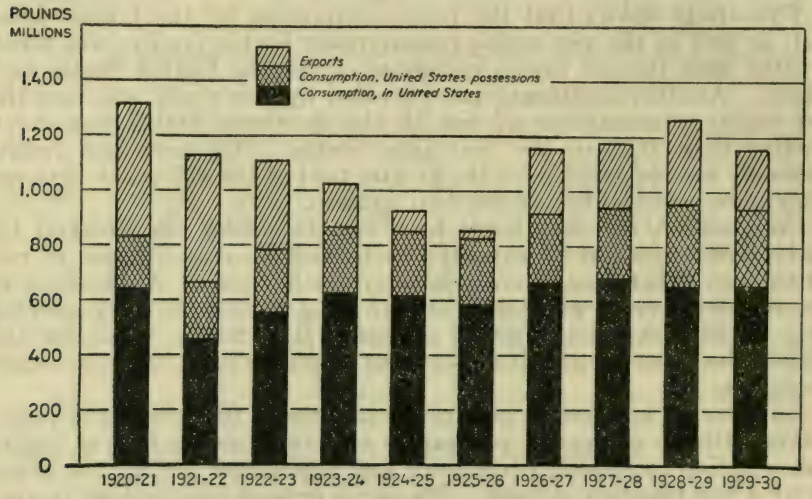

FIGURE 2.—CONSUMPTION IN THE UNITED STATES AND POSSESSIONS, AND EXPORTS OF UNITED STATES GROWN RICE 1920–21 TO 1929–30

There has been an upward trend in consumption in continental United States and insular possessions, during this 10-year period.

ticity. The exports of southern rice go to a large number of foreign markets. The quantity going to any one foreign market usually represents only a small part of the total amount of rice sold at that market, and therefore probably satisfies a demand which, though small, has a preference for that particular type of rice. That being the case, this rice does not to any great extent enter into competition with foreign rices in satisfying the foreign demand. This fact helps to explain why the price of Blue Rose in London is determined more by the supply of southern rice in the United States than it is by the supply of foreign rice available to satisfy the English demand. (Fig. 3.) The same is true in a lesser degree in other foreign markets. Cuba, however, is an exception to this general statement. In the Cuban market the competition between Blue Rose and Burma or other Asiatic rices is very keen. If, however, the supply of Blue Rose for export should become so large that a part of it would be forced onto less discriminating consumers, the competition of Indian and

other rices would be reflected in the price of Blue Rose not only in foreign markets but also in New Orleans and other United States markets. The magnitude of this preferential demand is difficult to determine, but experience shows that about 200,000,000 pounds can be absorbed annually in foreign markets when the price is 4 cents per pound for Fancy Blue Rose at New Orleans.

FACTORS AFFECTING THE PRICE OF SOUTHERN-TYPE RICE

Rice prices change from time to time because supply and demand, the factors which determine prices change with respect to each other. The relative importance of certain parts of demand and supply and their respective influences on prices is of most concern to the farmer.

Production in the United States from 1900 to 1914 was too small to satisfy domestic demand. During this period rice from India, Siam,

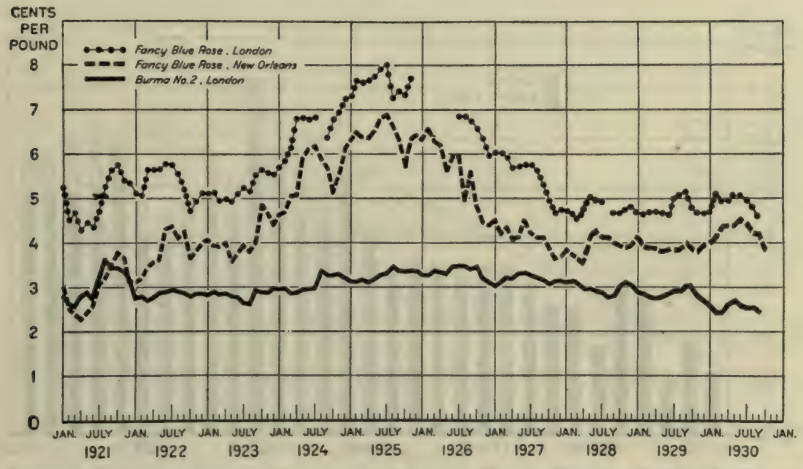

FIGURE 3.—WHOLESALE PRICE OF CLEANED RICE, FANCY BLUE ROSE, AT LONDON AND NEW ORLEANS, AND BURMA NO. 2 AT LONDON, 1921–1930

These two varieties and grades are representative of the American and Burma rices, respectively, sold in London and other European markets. Other Asiatic rice prices usually fluctuate with Burma prices in European markets.

and French Indo-China was consumed in large quantities in the United States. These foreign rices were cheaper than our own southern-type rice. Much of this cheap rice was consumed by people who do not eat rice when it is relatively high in price and in meeting this demand the foreign rice did not compete with the more expensive southern rice. There are, however, some people who will buy high-priced rice if cheap rice is not available, but if lower-priced rice can be obtained they buy it in preference to the higher. It was for this class of trade that the oriental rices competed with the southern-type rice and resulted in lower prices of southern rice than would have been obtained without foreign competition.

During this period, therefore, the supply factors affecting price were production in the United States and surplus production in Asia, mainly India. United States production was the more important of these two factors. Demand, which also must be taken into account

when determining price, was increasing at a rate of about 20,000,000 pounds annually.

With 1914 came a change in the status of the rice industry of the United States. (Fig. 4.) Prices improved through the period 1910 to 1914, and this improvement, together with the introduction of a better yielding variety, Blue Rose, resulted in a marked expansion of production which in turn brought lower prices. In fact, the expansion in production was nearly sufficient to meet domestic requirements.

Before 1914 the import duty on rice was effective. Since the demand for rice in continental United States is quite inelastic, the imposition of a duty probably had very little effect upon imports or consumption in the United States, and consequently most of the duty was added to the price the consumer had to pay for imported rice and also to the price the domestic producers received. The expansion in production reduced the dependence of the domestic market upon

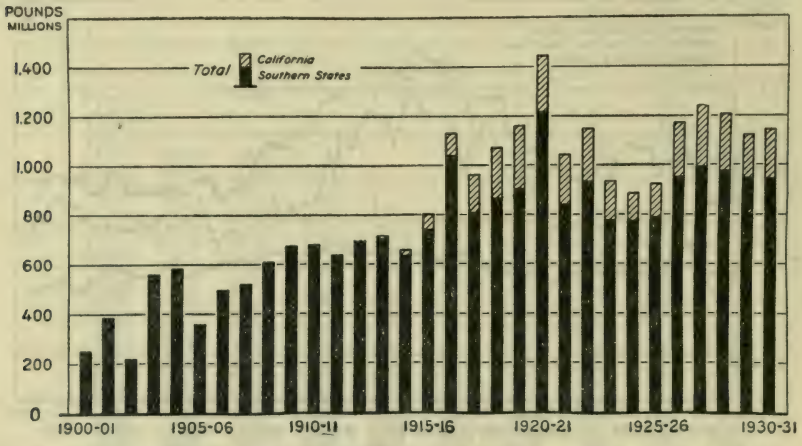

FIGURE 4.—DISTRIBUTION BETWEEN CALIFORNIA AND SOUTHERN STATES OF RICE PRODUCED IN THE UNITED STATES, 1900–1901 TO 1930–31

There was an upward trend in production from 1900 to 1920. From 1920 to 1930 the trend was practically level.

foreign supplies. This reduction in dependence was indicated by the great reduction in the importation of foreign rices. The expansion also brought domestic prices more closely into line with prices in foreign markets.

A new supply factor affecting the price of southern rice also became operative about this time. (Fig. 4.) California production reached sufficient size about 1914 to represent a significant competitive supply. In fact, by 1920 it had become so important that production in California, plus carry-over, affected prices of southern-type rice as much as southern production plus carry-over affected them. (Fig. 5.)

MONTHLY PRICES

The principal supply factor affecting average price of southern rice for the crop year is production in the United States plus carry-over. The supply factors affecting prices for various months of the year require a certain amount of additional explanation. It is known that factors of supply exert varying degrees of influence at different

times throughout the year. Since the first three or four months of the crop year constitute the transition period, or the period of adjustment between the supplies of the previous year and those of the new, the total supplies for the current year have little influence on prices during this period.

Beginning with November the total annual supplies exert an influence of some importance. This influence becomes stronger through December and January, reaching its peak in February. After February these supply factors begin to lose their influence. This loss is slow at first, but by June and July much of their influence has gone. This should not, however, be construed to mean that they have lost all their influence by July, because the current annual supplies have much more importance as price-determining factors during the latter part of the season than during the first three months.

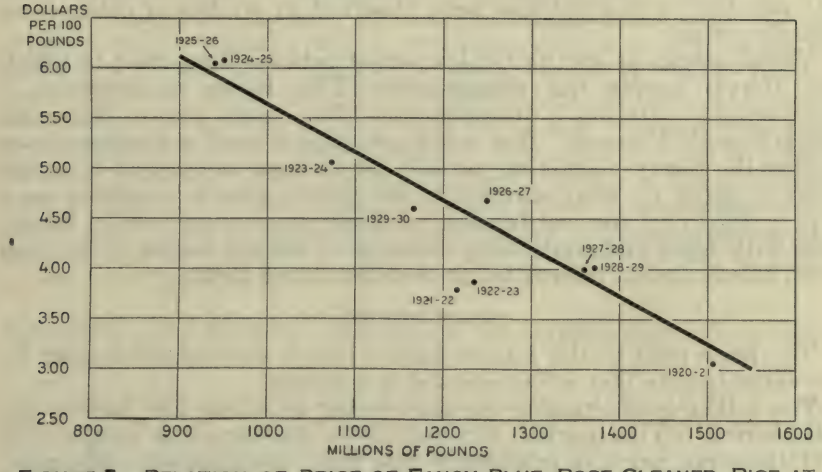

FIGURE 5.—RELATION OF PRICE OF FANCY BLUE ROSE CLEANED RICE AT NEW ORLEANS TO UNITED STATES SUPPLY, 1920–21 TO 1929–30

The line in this figure shows the average relationship between the price of Fancy Blue Rose at New Orleans (deflated by Bureau of Labor Statistics all-commodity index, 1926=100) and United States production plus carry-over for the crop years 1920–21 to 1929–30.

One reason why the current annual supply affects prices so little during the early part of the season is that its amount is not definitely known to the trade until a large part of the rough rice has been delivered to the mills. By the end of November normally about one-half of the year's crop is in the hands of millers and serves as a basis for an estimate of the entire production. This estimate apparently is accepted by the trade and influences prices. During September and October both buyers and sellers appear to be confused about the supply which will be available for the year. The result is that they pay much more attention to visible supply as determined by the carry-over from the previous year and the current receipts of rough rice. It is not supply but buyers' and sellers' information regarding supply that affects prices; therefore during this period, when information varies widely in accuracy, price may not behave as it would if accurate information on the prospective new crop were available to buyers and sellers.

Another factor which, because of the above-mentioned situation, appears to have an effect on price prior to November, is the experience of previous seasons. Many millers on the one hand and wholesale buyers of rice on the other let their trading practices be guided by their experience of the previous year. The influence of this factor is especially noticeable the first year following three successive years of rising or falling prices, causing prices during August, September, and October during those years to be closely related to previous years' prices.

After the annual domestic supply becomes definitely known to both miller and wholesale buyer, it can be relied upon practically to control price as long as it is used or disappears at a normal rate. If the disappearance is above the normal rate during the early part of the season and below the normal rate for the latter part, price will be affected accordingly. This factor affecting monthly prices is not peculiar to rice but has been observed in studies of other commodity prices.[5]

Visible stocks at any particular period indicate the extent to which the annual supply has disappeared. This factor is, however, a more reliable criterion of disappearance after a large part of the rough rice is in millers' hands. Not much attention is paid to disappearance during the heavy marketing period, but as soon as receipts of rough become small or stop altogether the visible stocks available as a supply until next harvest become relatively more important. Beginning with April and continuing throughout the remainder of the crop year, stocks are an influential price-determining factor.

FARM PRICES

The price paid to the farmer for his rice is determined largely by the same factors that affect cleaned-rice prices.

The miller is practically the only buyer to whom the farmer can sell his rice.[6] This market, fortunately for the farmer, is competitive and therefore price is practically free from monopolistic influences. If this were not true, rough-rice prices would not be expected to reflect consumer demand so completely as they do.

The price which a miller will pay for rough rice is determined largely by his milling costs and the price he receives for the rice and by-products after milling. The f. o. b. mill price paid for rough rice on any given day tends to be the same throughout the rice belt, because of the competition among millers. Occasionally a few mills may for short periods pay prices which are out of line with the price generally prevailing in other sections of the belt, but this does not disprove that there is a tendency toward a uniform price for a given quality of rough rice. Prices which are out of line often can be explained by local supply conditions.

Cleaned-rice prices were compared with prices of rough rice for each month during the marketing seasons of the years 1920 to 1928, inclusive. The farm price represented a smaller percentage of the price of cleaned when the latter was above the average for the 9-year period, and a larger percentage when below. This may be explained in part by the fact that millers considered their chances of losing to

[5] WORKING, H. FACTORS DETERMINING THE PRICE OF POTATOES IN ST. PAUL AND MINNEAPOLIS. Minn. Tech. Bul. 10, 41 p., illus. 1922.

[6] This statement does not apply to those farmers who are members of a cooperative association which mills the rice and makes returns to the farmer on a basis of the price received for cleaned rice.

be less when cleaned-rice prices were below the average and greater when above.

Although the current price of cleaned rice is used as a basis for determining the price of rough rice, it is obvious that the cleaned price one or two months in the future would be far more valuable. It is possible to forecast the price of cleaned rice one or two months in the future, but it is just as satisfactory to use the principal factor affecting that price, namely, production plus carry-over, to calculate the probable future price of rough rice.

Another factor which appears to be of importance during certain years is the rate of marketing rough rice. If farmers attempt to market their rice faster than at the normal rate (fig. 6) the tendency will be for the farm price to be less than if the normal rate of marketing had been followed. This is because mills have been built with milling and storage capacity to take care of normal receipts of rough rice, and if these capacities are taxed by abnormal receipts the price paid for rough probably will be lower. Furthermore, sales of cleaned rice are fairly well distributed throughout the year, and if the miller takes in more than the normal amount of rough rice early in the season he will necessarily have larger storage costs. The risk of price fluctuation between purchase of rough rice and sale of cleaned rice will be greater because the time interval will be longer. Cooperation among farmers selling rough rice should result in more economical marketing, which should enable the miller to utilize milling and storage capacities at a smaller cost per unit of rice handled and may be reflected in higher prices for rough rice.

FACTORS INFLUENCING THE PRICE OF CALIFORNIA-JAPAN TYPE RICE

Since the rice grown in California, known as California-Japan type, has a shorter and thicker kernel than that of southern rices and resembles that grown in Japan, the Japanese prefer it to the southern rice. Therefore a large part of the demand for California-grown rice comes from the Japanese who live in the western United States and in Hawaii. California, however, produces more rice than is normally demanded by that group of consumers. A portion of the remaining production is sold in other sections of the United States, but the greater part is exported to foreign countries, principally Japan.

When the price differential between Tokyo and San Francisco is sufficiently large, Japan takes practically all the California exportable surplus. During years when the spread between these two prices will not cover transportation costs and import duty very little California rice is exported to Japan. When Japan is not in the market for California rice, California must either seek other markets for its surplus or carry over a large percentage of the crop into the next year. (Figs. 7 and 8.)

California has been an important rice-producing State for a relatively short period. Only since the war has production exceeded domestic consumption and disposition of the surplus become one of the vital problems of the California rice-growing industry.

The consumption of California rice within the United States increased slightly during the nine years 1920–1928. The consumption in Hawaii during the same period increased relatively more than

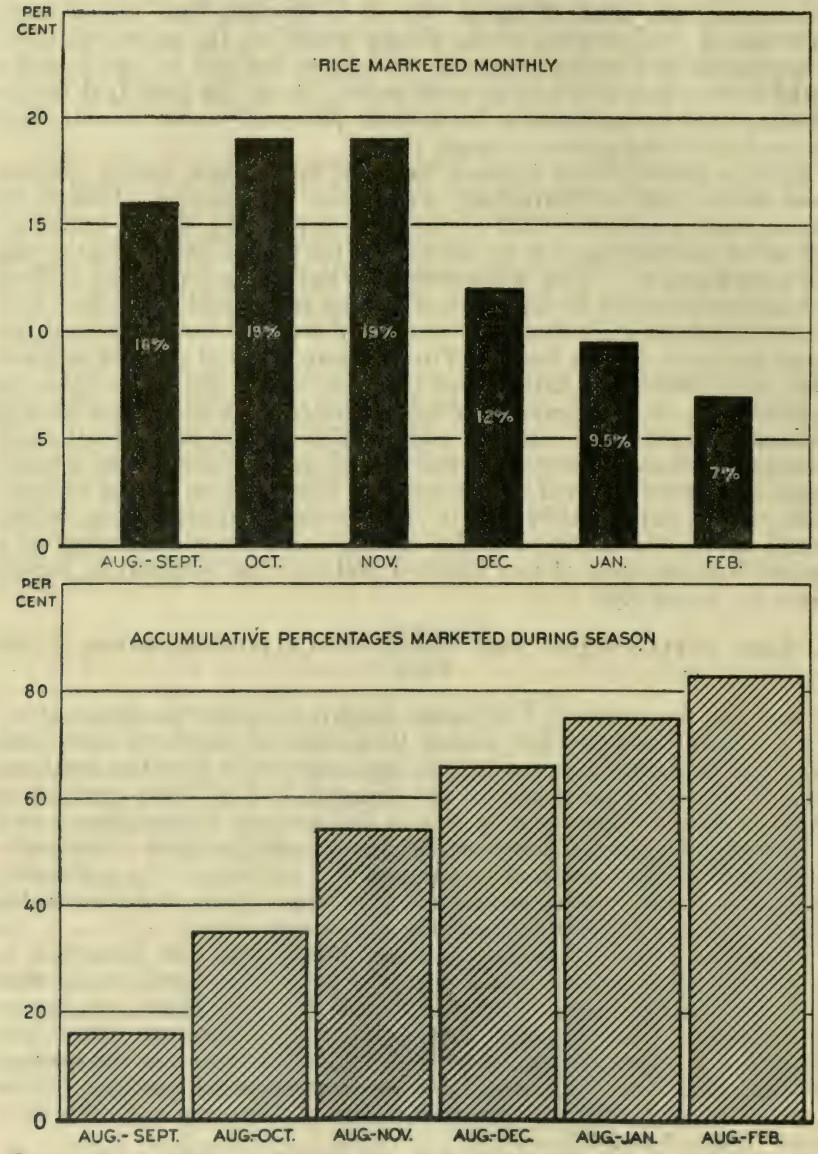

FIGURE 6.—PERCENTAGE OF ROUGH RICE MARKETED EACH MONTH AND ACCUMULATIVE PERCENTAGE MARKETED DURING MARKETING SEASON AVERAGE 1920–21 TO 1929–30

The data from which these figures were constructed were taken from the southern belt only. Rate of marketing is influenced by weather conditions at threshing time, percentage relationship of Early Prolific and Blue Rose to total crop, creditor control of sales, storage capacity available on farms, and farmers' predictions as to future prices.

in the continental United States. This increase in domestic demand has been due to a number of factors of which the two outstanding are (1) increase in population and (2) the tendency toward increased consumption of California rice by Japanese in the United States and

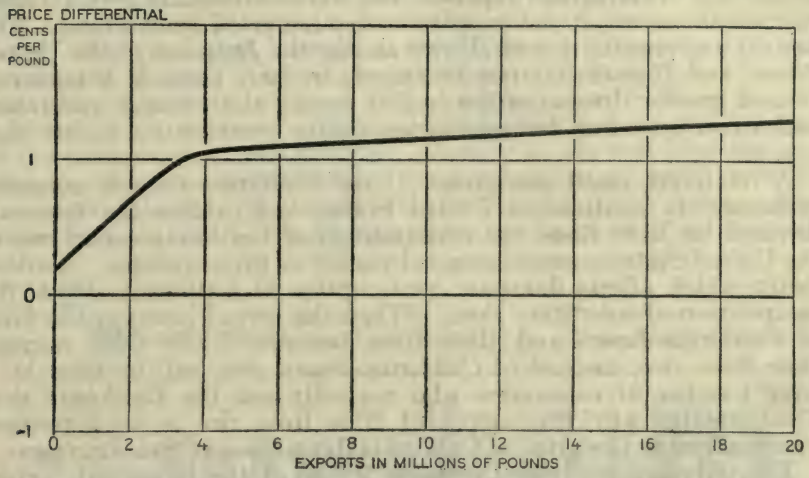

FIGURE 7.—RELATION OF BROWN-RICE PRICE DIFFERENTIAL (TOKYO ABOVE SAN FRANCISCO) TO EXPORTS FROM CALIFORNIA TO JAPAN, 1920–21 TO 1929–30

California exports to Japan are very small so long as the Tokyo price is less than 1 cent per pound above the San Francisco price.

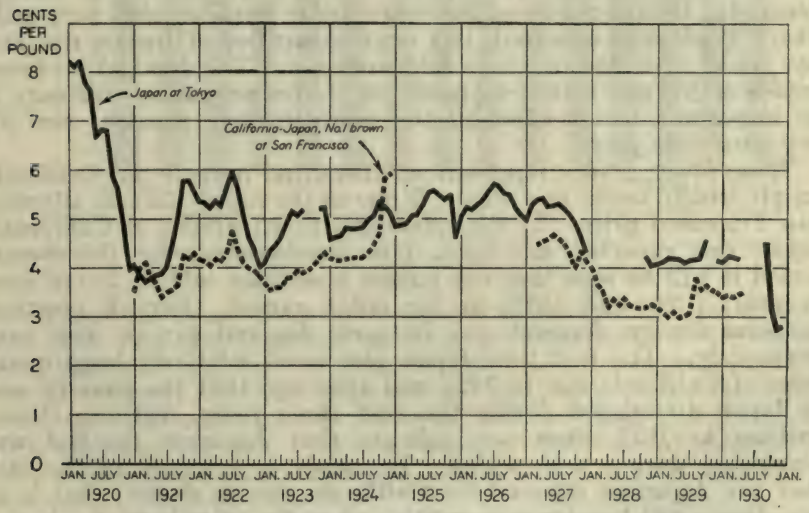
CENTS PER POUND
8
7
6
5
4
3
2
1
0
Japan at Tokyo
California-Japan, No.1 brown at San Francisco
JAN. JULY JAN. JULY JAN. JULY JAN. JULY JAN. JULY JAN. JULY JAN. JULY JAN. JULY JAN. JULY JAN. JULY JAN. JULY JAN. JULY JAN. JULY JAN.
1920 1921 1922 1923 1924 1925 1926 1927 1928 1929 1930

FIGURE 8.—WHOLESALE PRICE OF JAPAN RICE IN TOKYO AND CALIFORNIA-JAPAN RICE IN SAN FRANCISCO, BY MONTHS, 1920–1930

California Brown rice is sold principally to Japan. When Japan is out of the market, Brown-rice prices usually are not quoted on the San Francisco market.

Hawaii. It should be noted that the Japanese living in Japan prefer Japanese-grown rice to all other; those emigrating from that country carry that preference with them and demand rice imported from Japan. Children born of Japanese parents in the United

States and Hawaii do not retain this preference for Japanese rice and usually eat rice of a quality equal to the Japanese rice but costing less and grown in California. Since the prohibition of Japanese immigration and the relative increase of locally born in proportion to immigrant Japanese, the domestic demand for California rice has increased at the expense of rice imported from Japan. The per capita consumption of all rice among the Japanese in the United States and Hawaii has not increased; in fact, there is a tendency toward greater diversification in diet among the younger generation and a corresponding decrease in per capita consumption within that group.

A relatively small percentage of the California crop is normally consumed in continental United States and, unlike the domestic demand for Blue Rose, the consumption of California-Japan rice in the United States seems to respond readily to price changes. Another factor which affects domestic consumption of California rice is the competition of substitute rices. When the spread between the price of California-Japan and Blue Rose becomes wider than normal, Blue Rose rice, instead of California-Japan rice, will be used by a large number of consumers who normally eat the California rice. This explains why the supply of Blue Rose rice is an important factor affecting the price of California-Japan rice at San Francisco.

The influence of foreign demand is one of the important factors determining prices at San Francisco. It is rather difficult to measure accurately the foreign demand for California-grown rice. If only the grade Fancy Japan were under consideration, it might be possible to determine more accurately the increase or decrease in foreign demand. During many of the years under consideration very little Fancy grade was exported, but large quantities of Brown rice and low grades of milled rice were sold to Japan. The demand for lower grades or for any of the by-products of the rice-milling industry is an important factor affecting the representative price of rice for any particular year. [7]

These lower grades represent a substantial part of the California supply which, taken as a whole, is one of the supply factors affecting San Francisco price. If the quantities of all grades of California-Japan rice exported are taken into consideration for this 9-year period it will be seen that the largest quantities sold to Japan were in 1921, 1926, and 1922, in the order named. For all practical purposes foreign demand and Japanese demand can be used synonymously. The fact that Japan purchased relatively large quantities of California rice in 1921 and 1922 and that the amount sold to Japan diminished during the next three years, reaching almost nothing in 1925, does not indicate that Japanese demand was decreasing during that period. It merely is evidence of the fact that the Japanese demand for California rice is elastic; that is to say, Japan will buy large quantities when the price is relatively low and materially decrease her purchases as prices advance. The Japanese demand is of sufficient significance to California rice growers to justify a special study of the factors affecting price in the Japanese rice market.

[7] The average yearly price of Fancy Japan at San Francisco was chosen as the representative price of the total California production.

RICE PRICES IN JAPAN

Japan consumes more rice per capita than does any other country. A large percentage of the rice grown in Japan is consumed at or near the farm where it is produced. The remainder of the crop each year finds its way to the large rice markets of Osaka, Tokyo, and Kobe. The consumption of rice in Japan far exceeds the production in Japan proper. Large quantities are shipped in from the Japanese colonies of Taiwan (Formosa) and Chosen (Korea) and imported from Siam, French Indo-China, India, and the United States. (Fig. 9.)

About 55 per cent of the tillable land, 8,111,950 acres, was devoted to the production of rice in 1928. In spite of the fact that the consumption far exceeds production, the rice acreage, as well as production, has changed very little during the last eight years. Rice prices have not been a sufficient stimulant to cause a greater per-

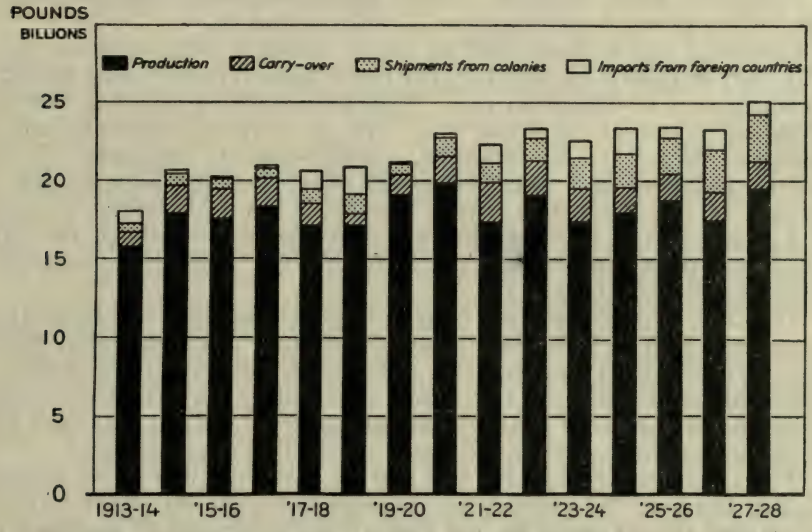

FIGURE 9.—ANNUAL SUPPLY OF RICE FOR JAPAN, 1913–14 TO 1929–30

Imports and inshipments from colonial possessions have tended to increase faster than production in Japan proper.

centage of the cultivable land to be used in rice growing nor to bring new land into rice production. The yield per acre, however, has been increased slightly. One of the principal reasons that Japanese rice prices have not risen high enough to stimulate increased production is the relatively low prices for which foreign and provincial rices can be purchased. There is, however, a preference for Japanese-grown rice, and foreign rices are purchased only at a substantial discount.

Since to eat Japanese rice is considered by the middle classes an evidence of social position, to eat foreign rice is to be degraded socially. The lower classes are more concerned about price than about social status and will buy foreign rice if it is much cheaper than Japanese rice. The order of preference for rice grown outside Japan appears to be as follows: Chosen-Japan, Taiwan-Japan, California-Japan (California-Japan and Taiwan-Japan types of rice

are about on a parity) and, least desired of the imported rices, those coming from southeastern Asia.

In the Japanese market California rice has an advantage over the rices from Siam, French Indo-China, and India so far as demand is concerned, but the Asiatic rices are much cheaper and consequently are sold in much larger quantities. In 1927 less than 8 per cent of the Japanese imports came from California, the remainder coming from Siam, India, and French Indo-China. The largest amount exported from California to Japan in any one year was 110,000,000 pounds in 1922, or 11 per cent of Japan's total importation.

California rice in Japan represents a relatively high percentage of the total value of imported rice because of its advantage in price over the Asiatic rices in the Japanese markets. California rice sells at about the same prices as Taiwan-grown Japanese rice. When California rice has been quoted on the Japanese markets it sold at a relatively small discount under Japanese-grown, middle-quality rice. The average discount was ½ cent per pound.

California rice is demanded for use in blending with Japanese rice. This fact enables it to sell at higher prices than if it were sold directly to consumers as California rice. This demand for California rice for blending exists at all times but only at certain discounts under Japanese rice. If, for example, middle-quality Japanese rice is selling in Tokyo at 1 cent per pound above California-Japan No. 1 Brown at San Francisco, there usually is some Japanese buying; and if the Tokyo price reaches 1.2 cents per pound above the San Francisco price, conditions are favorable for buying in relatively large quantities. (Fig. 7.)

The bulk of the Japanese buying in San Francisco has been at a price from 1.25 to 1.50 cents below the current price for Fancy California-Japan, thus making the differential between price paid in California and price of California rice selling on Kobe exchange between 0.31 and 0.47 cent per pound and from 0.83 to 0.97 cent per pound under the quotations of Japan rice in Japanese markets.[8]

The Japanese demand for rice can be described briefly by stating that in the past few years it has increased at a rate of about 450,000 koku (141,400,000 pounds) per year, mainly because of increases in population, with practically no increase in per capita consumption. Diversification of the diet of certain classes is resulting in greater consumption of foods other than rice, thus causing the per capita consumption of rice to remain stationary at about 330 to 340 pounds annually. A study of the influence of wages on price of rice leads to the following conclusions: An increase in the prosperity of the manufacturing industry, assuming a subsequent increase in wages, probably would result in an increased consumption of wheat and foods other than rice, whereas there probably would be no change or possibly a slight decrease in per capita consumption of rice. On the other hand a decrease in wages is likely to result in increased consumption of rice.

Japan has found it unprofitable to supply its own rice needs by home production. Therefore she has encouraged the production of Japanese-type rice in her colonies, Taiwan and Chosen. The com-

[8] The commission appointed in 1921 to regulate the price of rice in Japan has the power to buy and sell in any of the Japanese markets, to store rice, to require reports on stocks of both public and private warehouses, and to encourage or discourage imports. Exercising the last authority causes import duties to vary from time to time and thus influence the differential between San Francisco and Tokyo prices. The fluctuations of the rate of exchange of the yen also affect the differential.

bined production of Japan proper, Taiwan, and Chosen represents the Japanese-controlled supply and, as should be expected, is the most influential supply factor affecting the price of Japanese rice. In view of the fact that foreign rices must be imported to satisfy the Japanese demand the supply of these substitute rices, made up of production in Siam, French Indo-China, and India, is next in importance as a supply factor influencing the price of Japanese rice. The California supply has been too small as compared with these other supplies to exert any appreciable influence on Japanese price.

Japanese rice prices also tend to fluctuate with general wholesale prices.

STATISTICAL ANALYSIS OF FACTORS AFFECTING THE PRICE OF RICE

The first problem in this study was the selection of a price or prices representative for the rice industry. A series of either rough or cleaned rice prices could have been selected for the first analysis because the same factors were involved in either case. A series of cleaned-rice prices representative of the southern rice belt was chosen.

Although highly desirable, it would have been impracticable, if not impossible, to obtain a weighted average price of all southern rices passing through any one wholesale market. Therefore, a variety and grade which was representative of southern rices and for which it was possible to get reliable price data, was selected. For the period 1914 to 1930 Fancy Blue Rose was used; prior to 1914 Fancy Honduras. The prices studied were monthly and yearly averages as reported by the New Orleans Board of Trade, deflated by the Bureau of Labor Statistics all-commodity index of prices—base 1926 = 100.

The deflated price series was selected for analysis because it is that price rather than actual price which more nearly represents unit value of rice. The actual price of rice tends to change with the general level of prices of all commodities. The level of prices of all commodities changes because of one of two reasons or a combination of both: (1) The supply of currency changes, thus tending to change the quantity of other commodities for which a unit can be exchanged; (2) the relation of the supply of the commodities, representing the bulk of the sales of all commodities, to the demand for these commodities may change, so that the level of prices of all commodities may change. If the all-commodity price level advances because of the first reason, rice will tend to advance in price in approximately the same proportion. If the all-commodity price level advances because of the second reason, the price of rice will tend to rise because of the competition with other commodities selling at relatively higher prices. In either case the advance in rice prices due to advances in the all-commodity price level must be eliminated before an analysis of rice prices will reveal the price-making factors peculiar to rice.

Large quantities of the southern rices are exported annually, but the demand satisfied by this exportable surplus is not of sufficient importance to become a significant factor affecting price. If, however, the production of southern rices is materially increased in the future, the exportable surplus is quite likely to become an important price-making factor. Anticipating the need for world price-making information, a brief study of factors affecting the price of southern rices

in a world market was made. London was selected as a market in which world price-making factors operated and where large quantities of American southern-type rice are sold. The particular price studied was the yearly average for Fancy Blue Rose.

The study of rough-rice prices began with what had been learned of cleaned-rice prices and proceeded from that point. Inadequate price data prevented a study of rough-rice prices in each of the principal farmers' markets in the southern rice belt. Although they were the most nearly complete, New Orleans rough-rice prices were not used because it was felt that the price-making factors were not reflected in them so completely as in prices at markets nearer the producing centers; consequently a series consisting of the average of prices as of December 1 at a number of Louisiana markets was analyzed.

CALIFORNIA-JAPAN TYPE

In the California-Japan type study, as in the case of that of southern rices, the wholesale price of cleaned rice was analyzed first. Since practically all the California rice is of one variety the problem of choosing a representative variety was solved accordingly. The prices used were monthly and yearly averages of Fancy California-Japan at the San Francisco market, obtained from weekly reports in the Pacific Rural Press.

A relatively large percentage of the California crop normally is exported. It was therefore assumed that the San Francisco price probably was influenced by conditions existing in the foreign markets. Japan, being the principal purchaser of California rice, was logically the country in which one should look for conditions affecting the price of California rice. Tokyo was selected as a representative market. It was observed that there was a close relationship between the wholesale price of California-Japan rice in San Francisco and the price of certain rices in Tokyo. It was therefore necessary to find the factors affecting the price of a variety and grade of Japanese rice in Tokyo that was representative of the bulk of the rice consumed in Japan. For this study the average yearly price of Japan (brown) middle quality was selected.

PRELIMINARY ANALYSIS

The supply of rice to satisfy the domestic demand comes largely from the southern rice belt. The California production satisfies a certain portion of the domestic demand and is a potential substitute where Blue Rose is preferred. Therefore New Orleans prices are affected not only by the southern production but by the supply of California-Japan rice grown in California.

Since Blue Rose is consumed largely in certain sections of the United States, and California-Japan principally in other sections, a superficial analysis might lead to the conclusion that the New Orleans price would reflect the effect of all of the southern supply but little of the effect of the California supply. This however did not prove to be true. The New Orleans price reflects mill prices in the southern belt, which are affected by both southern and total United States supply.

In reality the supply of rice exerts an influence on the New Orleans price through information in the minds of buyers and sellers of rice on the stocks available or to be made available for satisfying their

demands. Therefore not only do the United States stocks and potential supply have to be considered, but the available supply and the probable future production of countries outside of the United States, all taken together, constitute supply factors affecting rice prices.

During the period 1900–1914, when large quantities of rice were being imported, the supplies in certain exporting countries exerted a pronounced influence on the United States price. By 1914 increases in United States production had practically driven foreign rices out of the domestic market.

Other supply factors affecting rice prices are supplies of substitute carbohydrate foods. Supplies of wheat, corn meal, and potatoes appeared to have an influence only when rice prices were extremely high, whereas no effect was detected when rice prices were low.

One of the first steps taken to determine the nature and magnitude of demand affecting price at New Orleans was to construct a curve representing as nearly as possible the relation of demand to price. It is impossible to construct an accurate demand curve from available data, since an accurate demand curve shows graphically the demand schedule for any given market for any given time during which supply and demand do not change, usually designated as an "instant of time."

Each price is represented by a point on the demand curve where the supply curve crosses. The ordinate of this point measures the price, while the abscissa measures the amount of the commodity demand. The yearly average price is represented by a point located on the total annual demand curve representing the average demand schedule for the year. It, however, gives no idea of the direction nor the curvature of the curve on which it is located. If it were possible to obtain similar data for other points on this total annual demand curve, a segment of the curve could be constructed.

The problem of constructing a demand curve for a period of years is probably more difficult. Using data for price and amount demanded, it is observed that for two successive years the price is the same, but for the latter year the amount sold is greater. It is quite obvious that it is impossible to construct a demand curve which will pass through both of these points, since the latter is located on a curve which presumably illustrates an increase in demand. Since the exact shape of the demand curve for the former year is unknown, it is impossible to measure the extent of increase in demand from the increase in length of the abscissa of a point on one demand curve over that of one located on another. This merely indicates the increase in demand at a given point on the curve and tells nothing about the distance between the two respective demand curves at their extremities. If there were some reason for assuming that the respective demand curves of the various years studied were parallel,[9] it would be more nearly correct to use the increased amount demanded at a given price as a measure of increase in demand. The general direction and curvature of the demand curve of a food commodity is due, in a large degree, to the food habits of those consuming the commodity.[10] If the food habits of these consumers have not changed materially during a certain period, it is only fair to assume that the demand curves during this same

[9] The term "parallel" is used in connection with two demand curves which have the same coefficient of elasticity and which do not coincide.

[10] Food habits are affected by many factors, one of which is the comparative prices of competing foods.

period have changed very little as regards their general direction and curvature; that is, they tend to be parallel.

For the above reason it is assumed that the difference in amounts demanded, price being held constant for the period studied (1914–1930), was a fair measure of increase or decrease in demand. The problem of getting the respective demand curves for the various years to coincide approximately is one of eliminating the effect of a general increase or decrease in demand. Observation showed that there was a general increase in demand during the period. By adjusting for annual increases in demand for the period 1914–1930 it was possible to determine the abscissas of various points assumed to be located on or near a curve representing the demand for the entire period.[11] The ordinates of these points had previously been adjusted by deflating

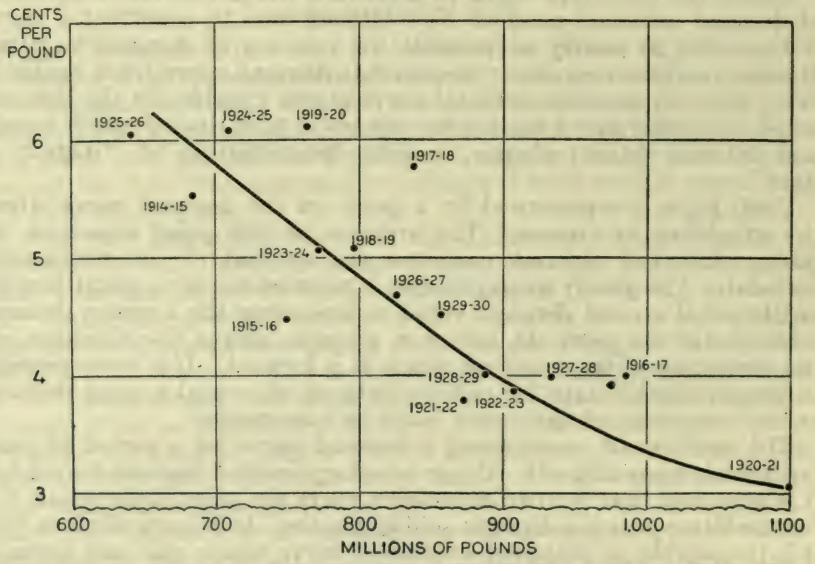

FIGURE 10.—RELATION BETWEEN DEFLATED PRICE OF FANCY BLUE ROSE RICE AT NEW ORLEANS AND SALES OF SOUTHERN RICE (TREND REMOVED), 1914–15 TO 1929–30

This curve shows the average effect of changes in rice prices upon sales of southern-grown rice.

the yearly average prices with the Bureau of Labor Statistics' all-commodity index of prices. A smoothed curve fitted to these points gives an approximation of a demand curve for rice at New Orleans as close as it was possible to obtain.

The "demand-approximation" curve shown in Figure 10 is only a portion of a curve which would illustrate the demand schedule of rice at the New Orleans market. It is, however, the only arc of the curve that is of significance in this study, since it explains the nature of the relationship between price and amount demanded for the period (1914–1930.) If it is desired to estimate the amount that would be demanded

[11] Because per capita consumption in the United States remained practically stationary from year to year during this period when yearly average prices changed very little, it was assumed that annual increases in sales or amounts demanded were due to increases in population and that an adjustment for increases in demand could be made by eliminating the effect of a trend fitted by the method of least squares to the annual sales.

at a price falling beyond the limits of the demand-approximation curve, this curve would be of little assistance.

It was necessary to construct this demand-approximation curve in order to obtain a perspective of the relation of demand to price, from which perspective it was possible to determine the methods that should be used in analyzing the effect of demand on price.

DETAILED ANALYSIS

It was observed that prices of Blue Rose in the foreign markets, where most of the southern-belt rices are sold, tended to fluctuate with domestic prices of Blue Rose rather than with prices of foreign-grown rices being sold in those markets. It was also noted that United States exports of southern-belt rices were influenced more by changes in domestic prices of Blue Rose than by changes in prices of foreign rices. From these two facts it was concluded that supplies of foreign rices did not influence prices of Blue Rose very much in either foreign or domestic markets. The supply factor which appeared to have the greatest influence on New Orleans price was domestic supply, consisting of United States production plus carry-over.

Domestic supply for the period 1914–1930 was adjusted by eliminating trend, fitted to the series by the method of least squares, so that the relation of this supply factor to price would be approximately the same as it would have been under conditions of no increase in demand.

From a preliminary scatter-diagram of adjusted domestic supply and price for the period 1920–21 to 1929–30 [12] it appeared that the normal relationship existed between supply and price, being represented by a function having a slight curve, similar to a logarithmic curve. The domestic-supply series, in millions of pounds, was changed to logarithms and correlated with yearly average price of Fancy Blue Rose at New Orleans for the period 1920–21 to 1929–30, with the results shown in Figure 11.

A supply factor representing the foreign rices which appeared to have a small influence on New Orleans prices of Blue Rose was introduced into the correlation. Indian production, unadjusted and expressed in billions of pounds, was used for the foreign supply factor.[13] The multiple correlation of yearly average price of Fancy Blue Rose at New Orleans (X_1) with the logarithms of domestic supply (X_6) and India production (X_7) resulted in a correlation coefficient of 0.985, which, when corrected for number of observations and independent variables, became 0.97. The average error of estimate was 12.7 cents per 100 pounds, or 2.82 per cent of the mean. (Fig. 12.) The regression equation was:

$$X_1 = 46.772 - 13.1997X_6 - 0.0273X_7$$

A series of prices was constructed by averaging the monthly prices of Fancy Blue Rose at New Orleans from November to July, inclusive,

[12] Because of the abnormal conditions existing during the war years the correlation study was confined to the postwar period.

[13] Burma actually supplies the greater part of the foreign rice competing with Blue Rose; but in view of the fact that deficit-producing Provinces of India buy principally from Burma and these purchases represent a relatively large percentage of all rice shipped out of Burma, it was concluded that the production in all India represented the foreign-supply factor affecting Blue Rose prices.

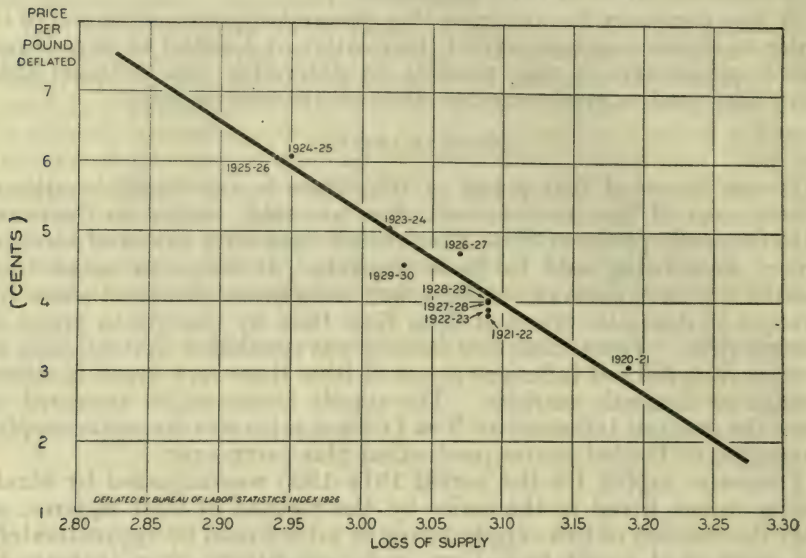

FIGURE 11.—RELATION BETWEEN AVERAGE PRICE OF FANCY BLUE ROSE CLEANED RICE AT NEW ORLEANS AND LOGARITHMS OF ADJUSTED SUPPLY IN THE UNITED STATES, 1920–21 TO 1929–30

The relationship between price and supply is shown by the regression of yearly price, Fancy Blue Rose at New Orleans, on logarithms of United States production plus carry-over, with trend (least squares) removed.

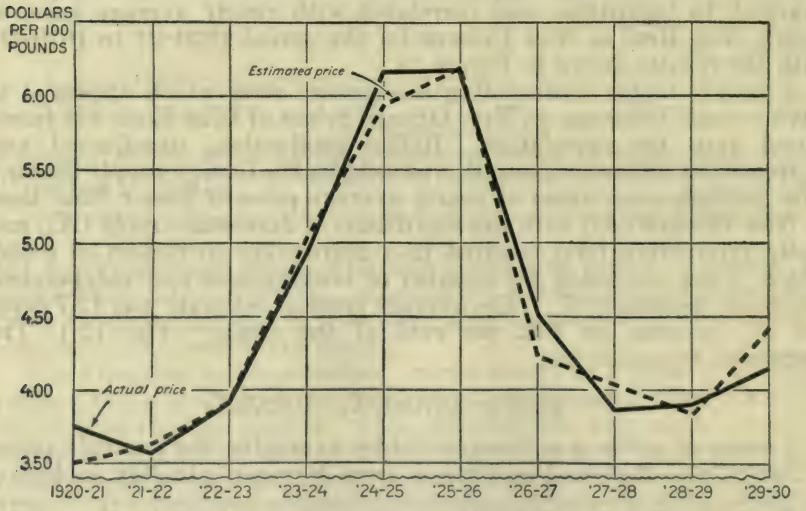

FIGURE 12.—ACTUAL AND ESTIMATED AVERAGE PRICE OF FANCY BLUE ROSE RICE AT NEW ORLEANS, 1920–21 TO 1929–30

Prices were estimated by the estimating formula developed in the correlation.

for each year (1920–21 to 1929–30). This price series was then used to replace the dependent variable in the yearly average-price correlation with the following results: Coefficient of correlation 0.9916, average error of estimate 11.2 cents per 100 pounds or 2.49 per cent. (Fig. 13.) The regression equation was as follows:

$$X_1 = 51.347 - 14.768X_6 - 0.024X_7$$

Two other periods, December-April and May-July were used and a price series was constructed for each. The results of correlating the December-April price series with the same independent variables used in the yearly correlation were as follows: Correlation coefficient 0.986, average error 15.4 cents per 100 pounds, or 3.51 per cent, and regression equation $X_1 = 51.324 - 15.2117X_2 - 00.0566X_7$.

A third independent variable (X_8), visible stocks of rough and cleaned rice as of May 1 (Table 20), was added to the two used in the

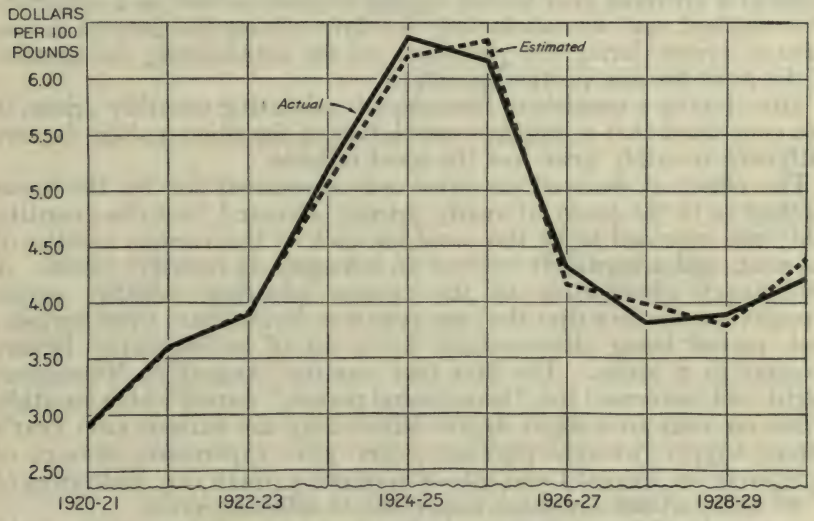

FIGURE 13.—ACTUAL AND ESTIMATED NOVEMBER-JULY PRICE OF FANCY BLUE ROSE RICE AT NEW ORLEANS, 1920–21 TO 1929–30

Price estimated from estimating formula developed in November-July price correlation.

yearly average price correlation and used in the May-July correlation. The following results were obtained: Coefficient of correlation 0.9828, average error of estimate 18.9 cents per 100 pounds or 3.99 per cent, regression equation $X_1 = 47.602 - 12.5687X_6 - 0.0454X_7 - 0.091X_8$.

MONTHLY PRICES

In the analysis of seasonal price fluctuations an attempt was made to isolate seasonal trends in monthly prices, characteristic of certain supply and demand combinations.

The average seasonal trend of prices was studied for each of three groups of years, each group being characterized by certain supply conditions.

(1) The first group consisted of those years in which a small crop followed a large crop.

(2) In the second group were those years in which a large crop followed a small crop.

(3) The third group was made up of years in which the crop was similar in size to the previous year's crop.[14]

The data used to construct the curve showing the characteristic seasonal trend of prices for each group were obtained as follows: The percentage relationship of each monthly price to the average price of the respective year was determined. From an arithmetic average of the percentages for each month a curve was constructed illustrating the average seasonal fluctuation of prices for the group.

A curve constructed from the modes of these percentages would be more representative of the group, but owing to the small number of years in each group a true mode was practically impossible to obtain. Because of the wide deviations of the percentages from their average, the average falls considerably short of being characteristic of the group. For purposes of forecasting the seasonal trend for any given year, more satisfactory results can be obtained if the seasonal trend of a previous year having similar supplies is used as a criterion. This method may be satisfactory for determining the general movement of prices during the year, but not for determining the amount of the price for any particular month.

After trying a number of methods of estimating monthly prices, it was concluded that a multiple correlation of the price-making factors with each monthly price was the most reliable.

The effect of demand on price was accounted for by the same method as in the study of yearly prices. Demand (not the quantity sold) was assumed to be the same for each of the various months of the year, and accordingly exerted an influence on monthly prices. A preliminary observation of the factors affecting monthly prices brought out the fact that the crop year was divided into three periods, each period being characterized by a set of price-making factors peculiar to it alone. The first four months, August to November, might well be termed the "transitional period," during which monthly prices are only to a slight degree affected by the current crop year's annual supply, whereas previous years' price experience, amount of carry-over on August 1 and rate of marketing rough rice, and prices of other commodities are most important in affecting price.

As a price-determining factor the importance of domestic supply for the current year advances with the season. It is the most influential factor during the second period, December to April. Domestic supply, however, is made up of southern-belt production plus carry-over in the South, added to California production plus California carry-over, and each of these exerts its own peculiar influence on price. In the case of the analysis of yearly average price, both of these supply factors can be combined into one factor, domestic supply, because practically all of the influence of each is exerted on price some time during the year. But when the price for each month from November to February is being analyzed these factors must be considered separately. During these months both southern supply and California supply are relatively significant in determining Blue Rose prices at New Orleans. Beginning with March, however, the California supply factor has lost the greater part of its influence, most of which has been gained by the southern-supply factor. In fact their respective influ-

[14] The terms "small," "large," and "similar" as above used are defined as follows: "Small" less than 90 per cent, "large" more than 110 per cent, "similar" not more than 110 per cent nor less than 90 per cent. All comparisons were made with trend removed.

ences on price from March to July are in about the same proportion as their relative contributions to the domestic supply, thus making it possible to combine the two into the domestic-supply factor to be used in the correlations with monthly prices from March to July, inclusive.

During the last period, April to July, inclusive, visible supply for the remainder of the year is a relatively important factor affecting prices. The same foreign-supply factor used in the yearly average price correlation was also used in each monthly price correlation, March to July, inclusive. It can be noted from Table 1 that the foreign-supply factor was of very little significance in any of the correlations. Table 1 gives the results of the correlations in which the dependent variable in each case was a deflated monthly price series (1920–1930) of Fancy Blue Rose at New Orleans. (Fig. 14.)

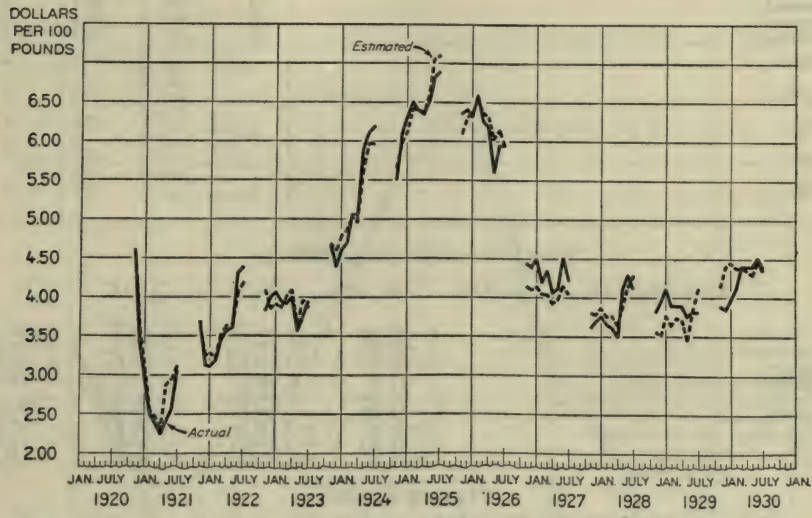

FIGURE 14.—ACTUAL AND ESTIMATED MONTHLY PRICE OF FANCY BLUE ROSE RICE AT NEW ORLEANS, 1920–1930

Prices were estimated from estimating formulas in Table 2. August, September, and October prices were not estimated.

The following independent variables were used: Logarithms of California production plus California carry-over expressed in millions of pounds represented by X_{12} in each of the correlations, November to February, inclusive; logarithms of southern production plus southern carry-over expressed in millions of pounds represented by X_{13} in each of the correlations, November to February, inclusive. A time series was used as an independent variable in each of the correlations, November to February, to account for the constant increase in demand. It consisted of a series of consecutive numbers beginning with 1 for 1920. The time series was represented by X_{14} in the correlations. Logarithms of total United States production plus carry-over expressed in millions of pounds, with trend (fitted by method of least squares) removed. This factor was represented by X_6 in all correlations from March to July, inclusive. Indian production expressed in millions of pounds and represented by X_7 was used in each correlation from March to July. Visible stocks of rough and cleaned rice expressed

in terms of pockets (100 pounds) or their equivalent and reported by the Rice Millers' Association as of the 1st day of each month, was used in each of the monthly correlations, respectively, from April to July. This factor was represented by X_8.

TABLE 1.—*Results of price correlations, November to July*

Month	Coefficient of correlation (actual)	Average error of estimate	
		Cents per 100 pounds	Per cent
November	R 0.967	18.1	4.13
December	R .964	22.1	5.05
January	R .971	22.0	5.01
February	R .992	12.4	2.84
March	r_{17}= .111 $R_{1.678}$= .993	10.3	2.32
April	r_{17}= .168 $R_{1.678}$= .995	9.8	2.21
May	r_{17}= .0782 $R_{1.678}$= .973	22.5	4.97
June	r_{17}= .0481 $R_{1.678}$= .978	21.4	4.46
July	r_{17}= .0656 $R_{1.678}$= .987	14.8	3.05

TABLE 2.—*Regression equations*

X_1=Constant $+b_{12.3\ldots n}X_2 +b_{13.2\ldots n}X_3, +b_{14.2\ldots n}X_4, +b_{n.2\ldots(n-1)}X_n$

November	X_1=32.698	$-6.165X_{12}$	$-4.292X_{13}$	$+0.041X_{14}$
December	X_1=38.086	$-7.305X_{12}$	$-5.293X_{13}$	$+.097X_{14}$
January	X_1=40.621	$-8.852X_{12}$	$-4.449X_{13}$	$+.129X_{14}$
February	X_1=47.22	$-10.643X_{12}$	$-5.018X_{13}$	$+.141X_{14}$
March	X_1=54.285	$-16.055X_6$	$-.01X_7$	
April	X_1=52.836	$-15.849X_6$	$+.006X_7$	$-.019X_8$
May	X_1=50.327	$-13.449X_6$	$-.052X_7$	$-.077X_8$
June	X_1=45.892	$-11.859X_6$	$-.052X_7$	$-.113X_8$
July	X_1=44.171	$-11.408X_6$	$-.048X_7$	$-.136X_8$

FARM PRICES

Prices paid for rough rice are affected by the same factors as are cleaned-rice prices. A simple correlation between Fancy Blue Rose prices and prices paid to producers during the same period for rough rice (an average of all grades) gave a correlation coefficient of 0.99.

The supply factors affecting rough-rice prices are the same as those affecting cleaned-rice prices. The quality factor which changes the ratio of a given supply of rough rice to the subsequent supply of cleaned rice tends to prevent these supply factors having the same effect on their respective prices. The demand for rough rice is in the nature of a derived demand, and because of this fact might have a slightly different effect on rough-rice prices than it has on cleaned-rice prices.

The only reliable series of prices for rough rice that could be obtained was that as of December 1, issued by the Division of Crop and Livestock Estimates, Bureau of Agricultural Economics, and published in the United States Department of Agriculture Yearbook. These prices are for an average of all grades of rough rice selling at that time.

A multiple correlation of the same independent variables used in the November-to-February monthly cleaned-rice price analysis, with Louisiana rough-rice prices as of December 1 deflated with Bureau of

Labor Statistics all-commodity price index (1926 = 100), yielded the following results:

Correlation coefficient 0.979. Average error of estimate was 3.9 cents per bushel, or 3.7 per cent of the mean. (Fig. 15.) The regression equation was:

$$X_1 = 7.746 - 1.323X_{12} - 1.201X_{13} + 0.016X_{14}$$

ACREAGE CHANGES DUE TO PRICES

The first section of this bulletin explains how prices are related to changes in farm-management practices among rice farmers. It therefore remains to record only the remainder of the analysis of the influence of prices on acreage changes.

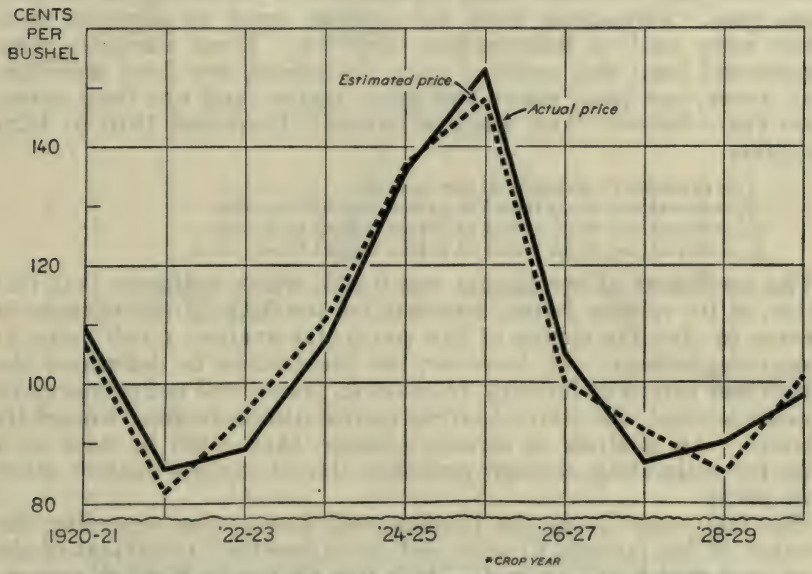

FIGURE 15.—ACTUAL AND ESTIMATED DECEMBER 1 PRICE PER BUSHEL OF ROUGH RICE RECEIVED BY PRODUCERS IN LOUISIANA, 1920–1929

Prices were estimated from estimating formula developed in farm-price correlation.

The prices used in the acreage study was United States farm price of rough rice as of December 1, divided by the Bureau of Labor's farm-products index. The index was used in part to reduce all prices within the series to a comparable basis. An increase in price in the adjusted series should indicate to the farmer that rice prices are higher as compared with commodities in general and that the spread between costs and price is greater. A number of farm crops are constantly competing for the use of farm land. Therefore, to determine the influence which rice prices have on changes in rice acreage, it is necessary to calculate the changes in rice prices with respect to other farm products. An increase in rice prices, for example, would not induce a farmer to keep land in rice the year it was scheduled for dry farming, if the price of the crops grown without irrigation had made a similar or greater increase. This comparison is made by dividing actual prices of rice by the farm-products index.

It was discovered that the adjusted series had a cyclical trend of the type illustrated in Figure 1. Therefore, it was concluded that the price factor affecting changes in acreage was deviations from this trend.

If the reasoning [15] is correct in regard to farmers' reactions to rice prices, changes in rice acreage can be accounted for as follows: Acreage will vary directly with prices one and three years previous and inversely with prices two years before.

A multiple correlation to test the accuracy of the above conclusions results in the following analysis:

The dependent variable was changes in rice acreage. Since it was necessary to take into account the effect of a secular trend, actual acreage changes were not used. In their stead link relatives were used, each year's acreage being expressed as a percentage of the previous year. Deviations from the cyclical trend of adjusted farm prices were used as independent variables. Three variables were constructed from this series of price deviations, one from previous-year prices, one from prices two years before, and one from prices three years before. This analysis covered the period 1910 to 1929 inclusive.

X_1=percentage changes in rice acreage.
X_9=deviations from trend of prices lagged one year.
X_{10}=deviations from trend of prices lagged two years.
X_{11}=deviations from trend of prices lagged three years.

The coefficient of correlation was 0.826, which indicates that this factor, in its various forms, accounts for too little of the changes in acreage to give the results of this particular analysis much value in forecasting acreage. If, however, the problem be to determine the nature and extent of farmers' reaction to prices, and not primarily to forecast acreage, the above analysis contributes something toward its solution. An analysis of acreage changes that could be used as a basis for estimating acreage probably should include factors other than price.

The fault may lie in the fundamental assumption regarding the reaction of rice farmers to price and the subsequent treatment of the price data used in the analysis. It is true that some farmers' acreage is practically determined by certain interested credit organizations, which may account for that acreage remaining unchanged when the majority is changing in response to the price stimulus.

The regression equation evolved from this correlation is as follows:

$$X_1 = 102.40188 + 1.006877X_9 - 0.08136943X_{10} + 0.51903049X_{11}$$

It should be noted that the regression coefficients of X_9 and X_{11} are positive, thus indicating that prices one and three years previous vary directly with acreage, whereas the minus coefficient of X_{10} indicates an inverse relationship for prices two years before.

Another point of interest in this study is the closeness with which each independent variable is associated with changes in acreage, shown as follows:

X_9 price lagged one year	$d_{12\cdot34}=0.507$.
X_{10} price lagged two years	$d_{13\cdot24}=0.0258$.
X_{11} price lagged three years	$d_{14\cdot23}=0.15$.

[15] See discussion on relation of farm price to acreage changes in the first part of this study.

PRICES OF CALIFORNIA-JAPAN TYPE

California-grown rice is consumed mainly in California, Hawaii, and in certain foreign countries, principally Japan. The quantity of rice purchased abroad by Japan is very large as compared to California's exportable surplus. Japan begins to buy California rice in rather large quantities when the differential between San Francisco and Tokyo price becomes favorable. It is therefore reasonable to assume that one of the factors affecting the price of California-Japan rice is the price of rice at Tokyo, Japan.

The competition of substitute rices, while an important factor at all times, assumes greater importance as the price of California rice rises; that is, the competition of Blue Rose, when Japan-type prices are relatively high, is such that demand for California-Japan falls off

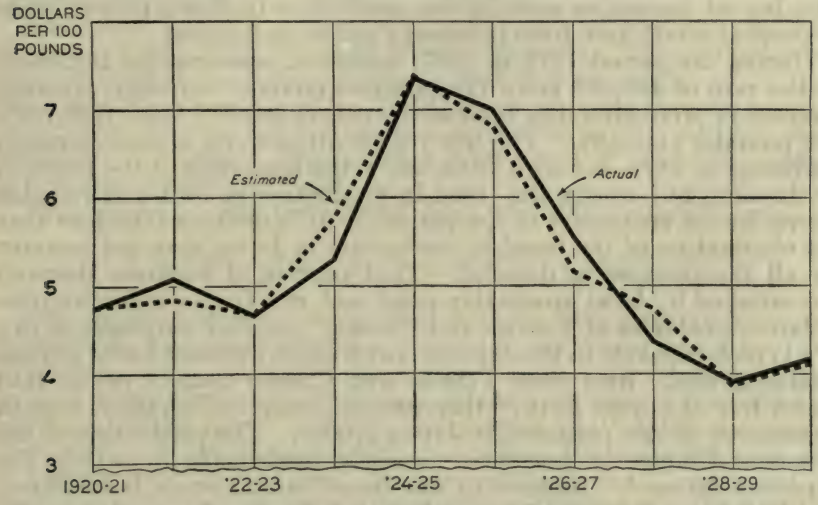

FIGURE 16.—ACTUAL AND ESTIMATED AVERAGE PRICE OF FANCY CALIFORNIA-JAPAN RICE AT SAN FRANCISCO, 1920–21 TO 1929–30

Price estimated from estimating formula developed in California-Japan price study.

rapidly when the differential between it and Blue Rose gets below normal. This suggests that the supply of the southern belt is another factor affecting California price. The supply of California-grown rice is obviously a factor affecting price.

A multiple correlation to measure the extent to which these factors affect San Francisco price for the period 1920–1930 gave a correlation coefficient of 0.9688, the average error being 18. 0 cents per 100 pounds, or 3.41 per cent. (Fig. 16.) The independent variables used were:

X_5 estimated yearly average price of middle-quantity Brown rice at Tokyo.
X_{12} logarithms of California production plus carry-over, in millions of pounds.
X_{13} logarithms of southern production plus carry-over, in millions of pounds.
X_{14} a time series beginning with 1 at 1920.

The dependent variable was San Francisco yearly average price of Fancy Japan deflated by Bureau of Labor's index of wholesale prices—

1926 = 100. The regression equation resulting from the above correlation was:

$$X_1 = 19.701 - 3.613X_{12} - 3.657X_{13} + 0.041X_{14} + 0.869X_5$$ [16]

RICE PRICES IN JAPAN

The amount consumed tends to vary inversely with the price. The fact that consumption increases during a period of years is not, in itself, evidence of increasing demand. If, however, it is found that the amount consumed increases during a period when the unit value or price remained constant, that is evidence of an increase in demand. Since demand exerts an influence on production through the medium of price, it is to be expected that production will increase as demand increases, of course with the lag inherent to the rice-growing industry. The law of increasing costs in rice production in Japan proper tends to prevent production from increasing so fast as demand.

During the period 1873 to 1927, inclusive, consumption increased at the rate of 450,000 koku (141,400,000 pounds) annually, whereas increase in production has been at the rate of 400,000 koku (125,700,000 pounds) annually. The line representing trend in consumption, beginning in 1873, is only a little below the beginning of the trend in production, but crosses the trend in production in 1881 and remains above for the remainder of the period.[17] It is obvious therefore that the elimination of the trend in production in Japan does not account for all the increase in demand. That portion of Japanese demand not satisfied by local production must seek rice from outside sources.

Japan's colonies of Taiwan and Chosen [18] produce surpluses of rice of a type acceptable to the Japanese, at a slight discount under Japan-produced rice. Rice from Taiwan and Chosen usually comes into Japan free of import duty;[19] therefore this source of supply is next in importance to rice produced in Japan proper. The production of the Japanese Empire is, however, normally inadequate to satisfy the Japanese demand. Imports of rice from Siam, French Indo-China, and India are next in importance in satisfying the Japanese demand. As a supply factor affecting price in Japan, production in these countries, rather than their exports to Japan, is the factor that exerts an influence on price. This is true because not only that rice which is sold to Japan, but the potential supply not sold but available for sale, affects price.[20]

The supply factors found to affect Tokyo price were: (1) Production in Japan proper, to which was added production in Taiwan and Chosen and the carry-over of all rices in Japan; (2) production in Siam, French Indo-China, and India. The latter factor was changed to logarithms in the correlation, because when a dot chart was made to show this supply factor and Tokyo price, the supply-price curve resembled a logarithmic curve.

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[16] A somewhat better correlation was obtained by substituting California production plus mill carry-over in millions of pounds (excluding carry-over in farmers' hands) for X_{12}, and eliminating X_{13}.

[17] Both trends were fitted to the data by the method of least squares for the period 1873–1927, inclusive.

[18] Taiwan has been part of the Japanese Empire since 1895 and Chosen since 1905. However, only since 1913 has Chosen enjoyed free trade with Japan proper.

[19] The price-stabilization commission may for short periods levy an import duty on colonial rice.

[20] Discussion of Indian production influence on New Orleans prices gives further reasons for using production rather than exports in the correlations.

The forces of supply and demand exert influences which determine the value of rice. However, because of the fluctuating value of money the price of rice, being value per unit expressed in money, may change while the value of rice remains constant. Rice prices may also change because of changes in the value of rice. This study is primarily for the purpose of measuring the changes in price of rice resulting from changes in the value of rice. The changes in price resulting from fluctuations in the value of money are accounted for in this correlation by using an index of wholesale prices in Japan as an independent variable.[21]

The period studied was from 1900 to 1927, inclusive, that being the longest period for which the data used were available. The price series studied was a yearly average price of middle-quality brown rice obtained by averaging monthly prices for the year October to September, inclusive.

The linear multiple correlation of production of Japanese Empire plus carry-over of all rice with trend removed as X_2, production of Siam, French Indo-China, and India with trend removed as X_3, and the index of wholesale prices in Japan as X_4, with yearly average price of middle quality brown rice at Tokyo as X_1, resulted in a coefficient of 0.9855.[22] The average error was 0.26 cent per pound, or 6.92 per cent of the mean.

The regression equation derived from the above correlation was—

$$X_1 = 7.615 - 0.28175\ X_2 - 2.0647\ X_3 + 2.29203\ X_4$$

The total determinate shows that while a large percentage of the fluctuations of price have been accounted for, there are some unaccounted for.[23] No doubt the errors occurred partly because the method used assumed a linear relationship between price and the principal supply factor, whereas the normal relationship is a curve. It is often possible to account for this curved relationship by the use of logarithms. If, however, the true function has a coefficient of elasticity greater or less than that of a logarithmic curve, the analysis can be accomplished with greater accuracy by the method of successive graphic approximations. The method of determining the index of multiple curvilinear correlation developed by Mordecai Ezekiel, of the Bureau of Agricultural Economics, United States Department of Agriculture, was followed.[24]

Multiple curvilinear correlation analysis proceeds from the point where the linear analysis, explained above, stops. It is an attempt to account for the error of estimate in the multiple linear correlation. By using the estimating formula $X_1 = 7.615 - 0.28175X_2 - 2.0647\ X_3 + 2.29203\ X_4$ the estimating value (X^1) for each observation was obtained. $X_1 - X_1{}^1 =$ the residual values (Z) with which this method deals. To obtain the curvilinear function in each of the three cases

[21] Index of wholesale prices obtained from the Bank of Japan, base 1900.

[22] Trend fitted by method of least squares for period 1900–1927, inclusive.

[23] Fair results were obtained for a shorter period, 1914–1927, when the actual price in yen per koku was deflated by the Bank of Japan's all-commodity index of prices and correlated with (1) production of Japan, Taiwan, and Chosen plus carry-over in Japan expressed in millions of koku; (2) production in India, Siam, and French Indo-China expressed in billions of pounds; and (3) a time series. The correlation coefficient was 0.9362 with an average error of 0.61 yen per koku or 8 per cent.

[24] EZEKIEL, M. A METHOD OF HANDLING CURVILINEAR CORRELATION FOR ANY NUMBER OF VARIABLES. Jour. Amer. Statis. Assoc. 19: [431]–453, illus. 1924.

of independent variables the following steps were taken in the order named.[25]

On a piece of graph paper the net regression line of X_1 on X_2 was constructed, then the residuals were plotted on the figure with their X_2 value for abscissa and the value of Z as ordinate from the net regression line as zero base.[26] For convenience in drawing a new net regression line the residuals were divided into groups along the old net regression line and an average value calculated for each group. A smooth curve connecting these averages would obviously give a new regression line which would fit equally as well as the old regression line and probably better. It was found, however, that any line that could be drawn through all of these average values would be a curve that did not correspond to the general shape of a function of price on this type of price-making factor. Keeping in mind the limitations on shape of curve that could be used in this case, a curve was drawn as close to the average of the residual values as possible and thus a net regression curve was constructed.

By the same method a net regression curve was constructed for X_1 on X_3. In the case of X_4 it was found that the linear net regression line fitted better than a curve.

The net regression curves referred to above are in reality only approximations to the true net regression curves. Only the linear effect of the remaining two independent variables in each case has been eliminated. It was necessary to make some adjustments in these first approximation curves to eliminate the curvilinear effect of the two remaining variables in each case. To do that it was necessary to obtain new estimates for X_1 and the resulting residuals.[27] Table 3 gives the results of these computations.

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[25] Mordecai Ezekiel has said to the author: "The problem in its simplest outlines may be stated as follows: Given a series of paired observations of the values of a dependent variable X_1, and two or more independent variables X_2, X_3, X_4, etc., required to find the change in X_1 accompanying changes in X_2, X_3, and X_4, in turn, while holding remaining independent factors constant, so that for any given values of X_2, X_3, and X_4, etc., values may be estimated for X_1, according to the regression equation

$$X_1 = a + f_2(X_2) + f_3(X_3) + f_4(X_4) + \text{etc.}$$

The expression '$f_2(X_2)$' is used here simply as a general term meaning any regular change in X_1 for given changes in X_2, whether describable by a straight line or a curve."

[26] The equation for the net regression line is as follows:

$$X_1 = a + b_2X_2 + b_3M_3 + b_4M_4$$

[27] New estimated values for X_1 (X_1'') based on curvilinear relationships were obtained by the formula—

$$X''_1 = a'_{1.234} + f'_2(X_2) + f'_3(X_3) + f'_4(X_4);$$ the constant $$a'_{1.234} = M_1 - \frac{\Sigma[f'_2(X_2) + f'_3(X_3) + f'_4(X_4)]}{N}$$

and the residuals by the formula $X_1 - X_1'' = Z''$. Formulas developed by Ezekiel.

TABLE 3.—*Results of computing X''_1 and Z''*

Year beginning Oct. 1	$f'_2(X_2)$	$f'_3(X_3)$	$f'_4(X_4)$	Σ	X''_1	X_1	Z''
1900–1901	3.95	3.92	1.89	9.76	2.21	1.89	−0.32
1901–2	3.44	3.97	1.89	9.30	1.75	2.03	+.28
1902–3	4.41	3.81	1.98	10.20	2.65	2.35	−.30
1903–4	3.76	3.90	2.12	9.78	2.23	2.08	−.15
1904–5	3.05	3.90	2.28	9.23	1.68	2.00	+.32
1905–6	3.44	3.91	2.39	9.74	2.19	2.28	+.09
1906–7	3.97	3.95	2.58	10.50	2.95	2.57	−.38
1907–8	3.74	3.97	2.53	10.24	2.69	2.60	−.09
1908–9	3.65	3.97	2.39	10.01	2.46	2.22	−.24
1909–10	3.52	3.81	2.42	9.75	2.20	1.95	−.25
1910–11	4.38	3.82	2.51	10.71	3.16	2.67	−.49
1911–12	3.86	3.84	2.64	10.34	2.79	3.17	+.38
1912–13	4.21	3.81	2.69	10.71	3.16	3.41	+.25
1913–14	3.71	3.76	2.62	10.09	2.54	2.86	+.32
1914–15	2.87	3.86	2.53	9.26	1.71	2.09	+.38
1915–16	3.11	3.41	3.03	9.55	2.00	2.07	+.07
1916–17	3.16	3.25	3.84	10.25	2.70	2.81	+.11
1917–18	3.73	3.11	5.12	11.96	4.41	4.49	+.08
1918–19	4.00	3.95	6.29	14.24	6.69	6.87	+.18
1919–20	3.57	3.76	8.01	15.34	7.79	7.89	+.10
1920–21	3.13	3.88	5.76	12.77	5.22	4.60	−.62
1921–22	3.98	3.55	5.81	13.34	5.79	5.95	+.16
1922–23	3.49	3.55	5.51	12.55	5.00	4.97	−.03
1923–24	3.71	3.89	5.90	13.50	5.95	5.87	−.08
1924–25	4.41	3.78	5.90	14.09	6.54	6.63	+.09
1925–26	4.36	3.86	5.28	13.50	5.95	6.19	+.24
1926–27	4.44	3.86	4.82	13.12	5.57	5.72	+.15
1927–28	4.32	3.89	4.80	13.01	5.46	5.26	−.20
Total	105.37	105.94	105.53	316.84	105.44	105.49	
Mean	3.7632	3.7836	3.77	11.32	3.77	3.77	
$a'_{1\cdot234}$				−7.55			

The standard deviation of Z'' is 0.266, whereas it was 0.3076 cent for the residuals of the linear computation, thus showing that the estimate based on curvilinear functions was more satisfactory than was the estimate from linear functions.

A second series of approximation regression curves was then constructed to determine the change in the estimates when the net curvilinear effect of the remaining independent variables is eliminated. The same method used to construct the first approximation curves was employed. The first approximation curves were used as net regression curves (the zero base) from which the Z'' values were plotted. After constructing the second approximation curves the values of X_1 corresponding to given values of each of the independent variables were read off from the function in the same manner as in the case of the first approximation curves. Table 4 shows the results of computations in obtaining the values of X_1 (X_1''') and the residuals (Z''') based on the second approximation curves. (Figs. 17 and 18.)

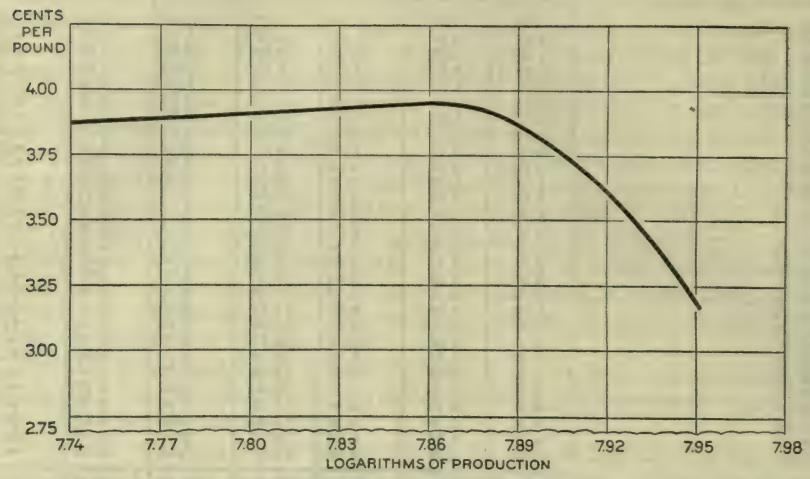

FIGURE 17.—RELATION BETWEEN PRICE OF MIDDLE-QUALITY BROWN RICE AT TOKYO AND PRODUCTION IN INDIA, SIAM, AND FRENCH INDO-CHINA, 1900–1901 TO 1927–28

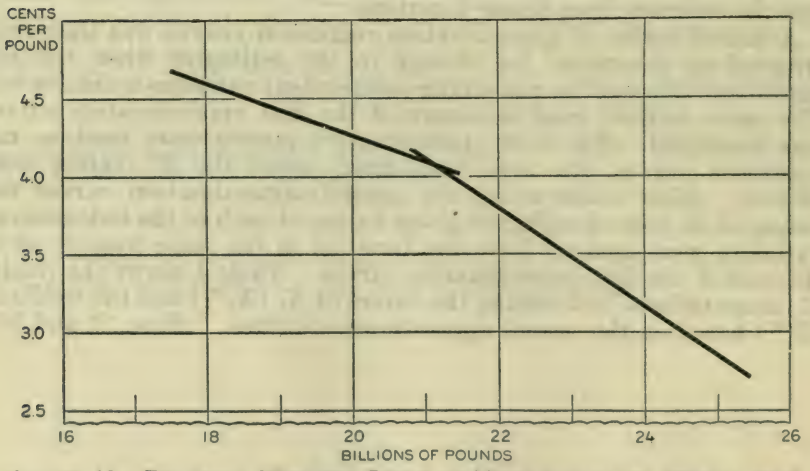

FIGURE 18.—RELATION BETWEEN PRICE OF MIDDLE-QUALITY BROWN RICE AT TOKYO, AND PRODUCTION PLUS CARRY-OVER IN THE JAPANESE EMPIRE, 1900–1901 TO 1927–28

Net regression of price of middle-quality Brown rice at Tokyo on two supply factors. Readings from these curves were used in making the price estimates shown in Figure 19.

TABLE 4.—*Results of computing X_1''' and Z'''*

Year beginning Oct. 1	$f_2''(X_2)$	$f_3''(X_3)$	$f_4''(X_4)$	Σ	X_1'''	X_1	Z'''
1900–1901	3.87	3.87	1.89	9.63	2.07	1.89	−0.18
1901–2	3.44	3.87	1.89	9.20	1.64	2.03	+.39
1902–3	4.36	3.90	1.98	10.24	2.68	2.35	−.33
1903–4	3.74	3.89	2.12	9.75	2.19	2.08	−.11
1904–5	3.06	3.89	2.28	9.23	1.67	2.00	+.33
1905–6	3.44	3.89	2.39	9.72	2.16	2.28	+.12
1906–7	3.97	3.87	2.58	10.42	2.86	2.57	−.29
1907–8	3.74	3.86	2.53	10.13	2.57	2.60	+.03
1908–9	3.63	3.86	2.39	9.88	2.32	2.22	−.10
1909–10	3.49	3.92	2.42	9.83	2.27	1.95	−.32
1910–11	4.25	3.92	2.51	10.68	3.12	2.67	−.45
1911–12	3.84	3.94	2.64	10.42	2.86	3.17	+.31
1912–13	4.13	3.92	2.69	10.74	3.18	3.41	+.23
1913–14	3.70	3.89	2.62	10.21	2.65	2.86	+.21
1914–15	2.94	3.94	2.53	9.41	1.85	2.09	+.24
1915–16	3.16	3.51	3.03	9.70	2.14	2.07	−.07
1916–17	3.17	3.35	3.84	10.36	2.80	2.81	+.01
1917–18	3.73	3.17	5.12	12.02	4.46	4.49	+.03
1918–19	3.98	3.87	6.29	14.14	6.58	6.87	+.29
1919–20	3.55	3.90	8.01	15.46	7.90	7.89	−.01
1920–21	3.17	3.90	5.76	12.83	5.27	4.60	−.67
1921–22	3.97	3.65	5.81	13.43	5.87	5.95	+.08
1922–23	3.44	3.65	5.51	12.60	5.04	4.97	−.07
1923–24	3.70	3.92	5.90	13.52	5.96	5.87	−.09
1924–25	4.36	3.90	5.90	14.16	6.60	6.63	+.03
1925–26	4.22	3.95	5.28	13.45	5.89	6.19	+.30
1926–27	4.51	3.95	4.82	13.28	5.72	5.72	+.00
1927–28	4.19	3.90	4.80	12.89	5.33	5.26	−.07
Total	104.75	107.05	105.53	317.33	105.65	105.49	
Mean	3.74	3.82	3.77	11.3332	3.77	3.77	
$a''_{1.234}$				−7.56			

The standard deviation of the last set of residuals (Z''') was 0.2488 cent, being somewhat smaller than in either of the former computations. Further approximation curves failed to reduce the standard deviation of the residuals, therefore it was concluded that the values of X_1 derived from the second approximation curves were the best that could be obtained by that method. The "Bruce adjustment" [28] was also tried, but no better results were obtained.

The next step was to calculate the index of correlation from the computations based on the last approximation curves. Using the formula

$$P=\sqrt{1.\frac{-\sigma^2_{z'''}}{\sigma^2_{X1}}}$$

the index of correlation was 0.9906 and the index of total determination was 0.9818. The average error was 0.201 cent per pound or 5.08 per cent of the mean of X_1. (Fig. 19.)

A larger part of the price fluctuations were accounted for during the latter half than during the first half of the period studied. (Fig. 19.) The greatest error of estimate for the latter half of the period was for 1920. The demand, owing to the post-war depression and falling off of employment, was less than normal and therefore caused estimated price, which was based on normal demand, to be higher than actual price.

The conclusions of the linear correlation were stated by means of the regression equation.

$$X_1=7.615-0.28175\ X_2-2.0647\ X_3+2.29203\ X_4$$

[28] This method consists merely of finding the function for the equation $X_1''''=\Theta\,[a+f_2'''(X_2)+f_3'''(X_3)+f_4'''(X_4)]$.

Since the regression curves used in the curvilinear correlation were of free-hand construction and can not be expressed by a mathematical equation, it is necessary to use some other form of expression.

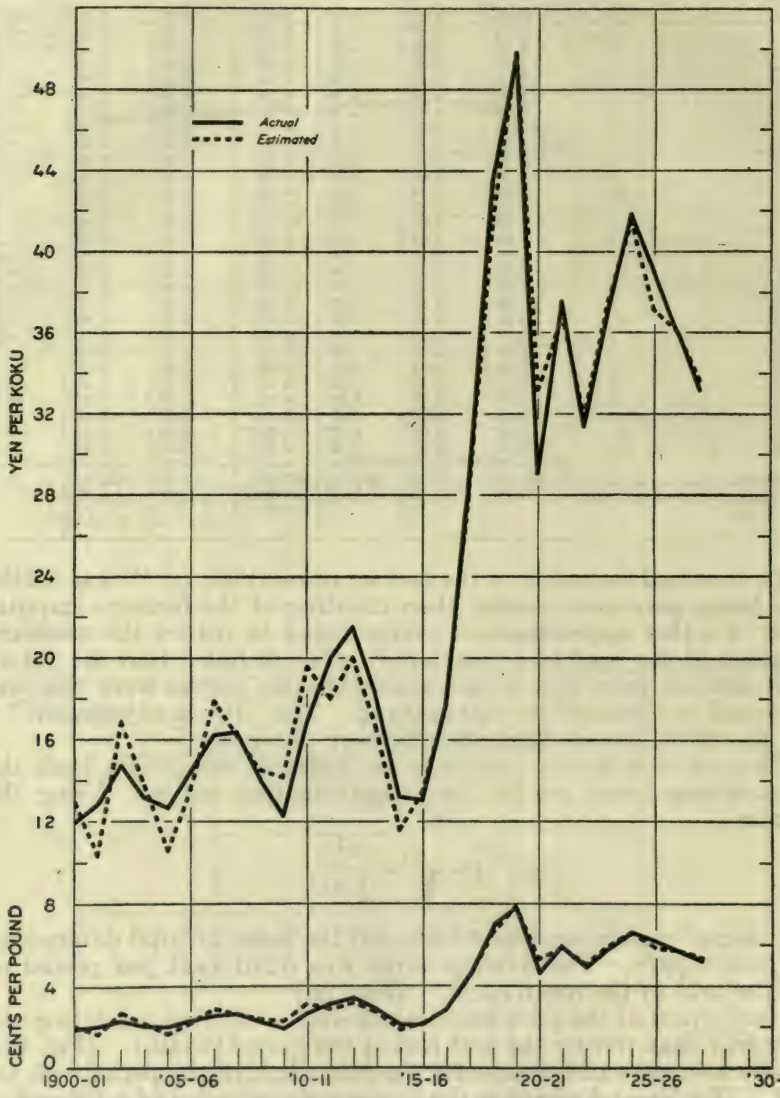

FIGURE 19.—ACTUAL AND ESTIMATED AVERAGE PRICE OF MIDDLE-QUALITY BROWN RICE AT TOKYO, 1900–1901 TO 1927–28

Prices were estimated from net regression curves developed in Tokyo price correlation.

In the following manner each of the functions is stated to show the value of X_1 associated with certain values of each independent variable when the other two are held constant at their respective means.

The most important independent variable is X_4; therefore it was decided to state the value of X_1 associated with given values of X_4 in

terms of actual values, whereas in the case of X_2 and X_3 the associated values are stated as deviations from the values, otherwise expected. The following formula developed by Mr. Ezekiel was used to obtain the actual values of X_1 associated with given values of X_4 with X_2 and X_3 held constant at their respective means. Let $F_4\ (X_4)$ represent the above-mentioned values of X_1, then

$$F_4\ (X_4) = f_4(X_4) - M_{f_4\ (X_4)} + M_1.$$

In view of the fact the function of X_1 on X_4 was the same as the net regression line calculated from the linear multiple correlation, it is possible to calculate the values for $f_4\ (X_4)$ by the following formula:

$$f_4\ (X_4) = 12.44 - 0.557699(M_2) - 12.911915(M_3) + 0.1446\ X_4.$$

The first formula can be further simplified in this case since $M_{f_4\ (X_4)}$ and M_1 have the same values they cancel leaving $F_4\ (X_4) = f_4\ (X_4)$.

If we use $F_2\ (x_2)$ and $F_3\ (x_3)$ to designate the deviations from the expected values of X_1 in the case of X_2 and X_3 respectively, then $X'_1 = F_4\ (X_4) + F_2\ (x_2) + F_3\ (x_3)$. To determine the value of $F_2\ (x_2)$ the following formula was used;

$$F_2\ (x_2) = f_2\ (X_2) - M_{f_2\ (X_2)}$$

Table 5 shows the results of this formula for each of the observations. $F_3\ (x_3)$ also was calculated by this formula and the results are shown in Table 6.

TABLE 5.—*Deviations of prices from those otherwise expected for* X_2

Year beginning Oct. 1	X_2	$f_2\ (X_2)$	$M_{f_2(X_2)}$	$F_2\ (x_2)$	Year beginning Oct. 1	X_2	$f_2\ (X_2)$	$M_{f_2(X_2)}$	$F_2\ (x_2)$
1900–1901	21.7	3.87	3.74	0.13	1914–15	24.9	2.94		−0.80
1901–2	23.2	3.44		−.30	1915–16	24.0	3.16		−.58
1902–3	19.4	4.36		.62	1916–17	23.9	3.17		−.57
1903–4	22.0	3.74		.00	1917–18	22.1	3.73		−.01
1904–5	24.3	3.06		−.68	1918–19	21.4	3.98		.24
1905–6	22.8	3.44		−.30	1919–20	22.6	3.55		−.19
1906–7	21.4	3.97		.23	1920–21	23.9	3.17		−.57
1907–8	22.0	3.74		.00	1921–22	21.4	3.97		.23
1908–9	22.3	3.63		−.11	1922–23	22.8	3.44		−.30
1909–10	22.8	3.49		−.25	1923–24	22.2	3.70		−.04
1910–11	20.1	4.25		.51	1924–25	19.4	4.36		.62
1911–12	21.8	3.84		.10	1925–26	20.3	4.22		.48
1912–13	20.9	4.13		.39	1926–27	18.6	4.51		.77
1913–14	22.3	3.70		−.04	1927–28	20.5	4.19		.45

TABLE 6.—*Deviations of prices from those otherwise expected for* X_3

Year beginning Oct. 1	X_3	$f_3\ (X_3)$	$M_{f_3(X_3)}$	$F_3\ (x_3)$	Year beginning Oct. 1	X_3	$f_3\ (X_3)$	$M_{f_3(X_3)}$	$F_3\ (x_3)$
1900–1901	0.8041	3.87	3.82	0.05	1914–15	0.8751	3.94		0.12
1901–2	.7745	3.87		.05	1915–16	.9289	3.51		−.31
1902–3	.8363	3.90		.08	1916–17	.9465	3.35		−.47
1903–4	.8129	3.89		.07	1917–18	.9513	3.17		−.65
1904–5	.8149	3.89		.07	1918–19	.7938	3.87		.05
1905–6	.8136	3.89		.07	1919–20	.8882	3.90		.08
1906–7	.7875	3.87		.05	1920–21	.8414	3.90		.08
1907–8	.7466	3.86		.04	1921–22	.9165	3.65		−.17
1908–9	.7505	3.86		.04	1922–23	.9180	3.65		−.17
1909–10	.8802	3.92		.10	1923–24	.8420	3.92		.10
1910–11	.7785	3.92		.10	1924–25	.8837	3.90		.08
1911–12	.7768	3.94		.12	1925–26	.8681	3.95		.13
1912–13	.8808	3.92		.10	1926–27	.8621	3.95		.13
1913–14	.8915	3.89		.07	1927–28	.8344	3.90		.08

Table 7 shows the result of computing the values of X_1 associated with given values of X_4 when the values of X_2 and X_3 were held at their respective means, and the deviations of X_1 values from those otherwise expected for given values of X_2 and X_3 respectively. X'_1 was computed by the following formula:

$$X'_1 = F_4\ (X_4) + F_2\ (x_2) + F_3\ (x_3).$$

TABLE 7.—*Computed values of* X_1

Year beginning Oct. 1	$F_4\ (X_4)$	$F_2\ (x_2)$	$F_3\ (x_3)$	X'_1	X_1	Z
1900–1901	1.89	0.13	0.05	2.07	1.89	0.18
1901–2	1.89	−.30	.05	1.64	2.03	+.39
1902–3	1.98	.62	.08	2.68	2.35	−.33
1903–4	2.12	.0	.07	2.19	2.08	−.11
1904–5	2.28	−.68	.07	1.67	2.00	+.33
1905–6	2.39	−.30	.07	2.16	2.28	+.12
1906–7	2.58	.23	.05	3.86	2.57	−.29
1907–8	2.53	.0	.04	2.57	2.60	+.03
1908–9	2.39	−.11	.04	2.32	2.22	−.10
1909–10	2.42	−.25	.10	2.27	1.95	−.32
1910–11	2.51	.51	.10	3.12	2.67	−.45
1911–12	2.64	.10	.12	2.86	3.17	+.31
1912–13	2.69	.39	.10	3.18	3.41	+.23
1913–14	2.62	−.04	.07	2.65	2.86	+.21
1914–15	2.53	−.80	.12	1.85	2.09	+.24
1915–16	3.03	−.58	−.31	2.14	2.07	−.07
1916–17	3.84	−.57	−.47	2.80	2.81	+.01
1917–18	5.12	−.01	−.65	4.46	4.49	+.03
1918–19	6.29	.24	.05	6.58	6.87	+.29
1919–20	8.01	−.19	.08	7.90	7.89	−.01
1920–21	5.76	−.57	.08	5.27	4.60	−.67
1921–22	5.81	.23	−.17	5.87	5.95	+.08
1922–23	5.51	−.30	−.17	5.04	4.97	−.07
1923–24	5.90	−.04	.10	5.96	5.87	−.09
1924–25	5.90	.62	.08	6.60	6.63	+.03
1925–26	5.28	.48	.13	5.89	6.19	+.30
1926–27	4.82	.77	.13	5.72	5.72	.00
1927–28	4.80	.45	.08	5.33	5.26	−.07

SUMMARY

The size of the United States rice crop, together with carry-over in the United States, is the most important factor affecting domestic prices of rice. The general level of prices of other commodities is also an influential factor. California production is as important as southern production during certain periods of the year on prices of southern rice. Rough rice prices tend to move with prices of milled rice when rough rice is being marketed at a normal rate.

Changes in rice acreage in the southern belt are affected by the prices of rice that have prevailed during the previous three years. The price one year before exerts the most influence. The practice of dry farming or fallowing land every third year to rid it of red rice makes it impracticable for changes in acreage to follow price changes more closely. Acreage changes in the California rice area are closely associated with prices of rice the year before and with the quantity of water available for irrigation.

Consumption of rice per capita in the United States is low. It does not seem likely that there will be any considerable change in the near future, but total national consumption will probably increase because of increases in population. The southern States supply from 80 to 85 per cent of the rice consumed in continental United States, and practically all of the remainder comes from California.

Imports supply about 2 per cent. Porto Rico is a large buyer of rice grown in the United States. About 90 per cent of the Porto Rican trade is supplied by the southern States; 10 per cent or less comes from California. Hawaii takes relatively large quantities of rice grown in the United States each year; practically all of this is supplied by California. The domestic market, consisting of continental United States and insular possessions, normally takes between 900,000,000 and 1,000,000,000 pounds of the United States crop each year. The quantity is affected only slightly by the rise and fall of prices.

Rice grown in the United States is exported to a relatively large number of foreign countries. The total quantity exported varies inversely with prices. The largest yearly export during the 11-year period 1920–21 to 1930–31 was 511,000,000 pounds in 1921–22 when New Orleans price for Fancy Blue Rose averaged $3.57 per 100 pounds. The smallest quantity exported during any year of this period was 28,000,000 pounds in 1925–26 when the New Orleans price averaged $6.18. In foreign markets southern rice competes with rice grown in Burma, Siam, and French Indo-China; the lower grades of Blue Rose suffer most from this competition which is probably most keenly felt in the Cuban market.

California rice is exported mainly to Japan. Japan normally produces less rice than it consumes. The deficit is supplied in part from rice grown in Taiwan and Chosen and in part by importations from Asiatic surplus-producing countries and the United States. Rice is imported from the United States (California) in relatively large quantities only when the price of middle-quality Brown rice at Tokyo is about 1 cent per pound higher than the price of No. 1 Brown at San Francisco. Rice price changes in Tokyo are affected mainly by changes in supplies of rice grown in Japan, Taiwan, and Chosen and by changes in production of rice in Siam, French Indo-China, and India. Price changes of California rice at San Francisco are influenced principally by production plus carry-over in California and by changes in prices of Blue Rose at New Orleans and changes in Japanese rice prices at Tokyo.

APPENDIX

TABLE 8.—*Rice acreage, production, average price per bushel received by producers, and carry-over in the United States, 1904–5 to 1930–31*

Year beginning Aug. 1	Acreage	Average yield per acre	Production		Average price received by producers Dec. 1	Carry-over rough and cleaned Aug. 1
			Rough	Cleaned		
	1,000 acres	*Bushels*	*1,000 bushels*	*1,000,000 pounds*	*Cents*	*1,000,000 pounds*
1904–5	662	31.9	21,096	586	65.8	----------
1905–6	482	28.2	13,607	378	95.2	----------
1906–7	575	31.1	17,855	496	90.3	----------
1907–8	627	29.9	18,738	521	85.8	----------
1908–9	655	33.4	21,890	608	81.2	----------
1909–10	610	33.8	20,607	572	79.6	----------
1910–11	723	33.9	24,510	681	67.8	----------
1911–12	696	32.9	22,934	637	79.7	----------
1912–13	723	34.7	25,054	696	93.5	----------
1913–14	827	31.1	25,744	715	85.8	----------
1914–15	694	34.1	23,649	657	92.4	11
1915–16	803	36.1	28,947	804	90.6	34
1916–17	869	47.0	40,861	1,135	88.9	36
1917–18	981	35.4	34,739	965	189.6	16
1918–19	1,119	34.5	38,606	1,072	191.8	1
1919–20	1,063	39.5	41,985	1,166	266.6	17
1920–21	1,336	39.0	52,066	1,446	119.1	61
1921–22	921	40.8	37,612	1,045	95.2	186
1922–23	1,055	39.2	41,405	1,150	93.1	90
1923–24	895	37.7	33,717	937	110.2	137
1924–25	850	37.9	32,206	895	138.6	48
1925–26	883	37.7	33,249	924	153.8	16
1926–27	1,034	41.1	42,477	1,180	109.6	90
1927–28	1,003	44.6	44,754	1,243	92.9	115
1928–29	956	45.4	43,440	1,207	88.5	171
1929–30	868	46.6	40,462	1,124	97.7	117
1930–31	960	43.1	41,367	1,149	76.4	80

Compiled from records of the Division of Crop and Livestock Estimates with the exception of carry-over, which was compiled from the annual report of the Rice Millers' Association.

TABLE 9.—*Rice acreage, yield per acre, production, and average price per bushel received by producers, by States, 1910–11 to 1930–31*

Year beginning Aug. 1	Louisiana				Arkansas				Texas				California			
	Acreage	Average yield per acre	Production	Price Dec. 1	Acreage	Average yield per acre	Production	Price Dec. 1	Acreage	Average yield per acre	Production	Price Dec. 1	Acreage	Average yield per acre	Production	Price Dec. 1
	1,000 acres	*Bushels*	*1,000 bushels*	*Cents*	*1,000 acres*	*Bushels*	*1,000 bushels*	*Cents*	*1,000 acres*	*Bushels*	*1,000 bushels*	*Cents*	*1,000 acres*	*Bushels*	*1,000 bushels*	*Cents*
1910–11	371	34.4	12,769	67	60	40.0	2,400	70	265	33.0	8,738	68	(1)	33.0	3	65
1911–12	371	31.5	11,693	79	72	39.0	2,792	82	238	34.3	8,174	80	(1)	40.0	6	75
1912–13	353	33.5	11,812	93	91	37.5	3,405	94	266	35.5	9,429	94	1	50.0	70	91
1913–14	406	29.0	11,760	84	105	36.0	3,769	90	303	32.0	9,696	86	6	48.0	293	100
1914–15	336	32.1	10,802	93	93	39.8	3,685	90	240	33.8	8,102	92	15	53.3	800	100
1915–16	401	34.2	13,714	90	100	48.4	4,840	95	260	30.5	7,930	89	34	66.7	2,268	90
1916–17	443	46.0	20,392	90	125	50.5	6,312	96	235	45.0	10,575	86	58	59.0	3,422	78
1917–18	500	31.0	15,500	190	152	41.0	6,232	190	238	30.0	7,140	200	83	68.0	5,644	175
1918–19	580	28.8	16,704	195	170	37.9	6,443	180	245	32.0	7,840	197	112	65.5	7,336	190
1919–20	527	35.2	18,550	271	147	46.0	6,762	240	217	32.0	6,944	280	155	60.0	9,300	267
1920–21	700	36.0	25,200	110	175	49.0	8,575	131	281	34.0	9,554	125	162	51.0	8,262	121
1921–22	480	36.0	17,280	86	125	53.5	6,688	92	166	36.1	5,993	101	135	54.0	7,290	115
1922–23	555	36.0	19,980	89	154	48.0	7,392	88	191	31.2	5,959	90	140	55.0	7,700	110
1923–24	495	33.5	16,582	107	135	39.5	5,332	112	145	40.0	5,800	115	106	53.5	5,671	112
1924–25	440	34.6	15,224	136	164	42.0	6,888	138	146	38.0	5,548	125	90	48.5	4,365	166
1925–26	430	33.3	14,319	153	175	43.0	7,525	150	162	38.0	6,156	149	103	46.6	4,800	170
1926–27	501	32.5	16,282	105	199	53.0	10,547	100	166	41.5	6,889	110	149	53.6	7,986	131
1927–28	500	40.0	20,000	87	175	44.0	7,700	90	165	48.6	8,019	86	160	56.0	8,960	115
1928–29	487	38.8	18,896	90	164	47.7	7,823	86	163	50.0	8,150	88	132	61.9	8,171	88
1929–30	472	39.9	18,833	98	156	51.0	7,956	92	144	51.5	7,416	97	95	65.5	6,222	105
1930–31	491	36.0	17,676	75	172	46.0	7,912	73	186	45.5	8,463	77	110	66.1	7,271	83

Compiled from records of the Division of Crop and Livestock Estimates.
[1] Less than 500 acres.

TABLE 10.—*Rice consumption in the United States and possessions, United States exports, and total consumption of United States rice, 1918–19 to 1929–30*

Year beginning Aug. 1	Consumption in the United States and possessions											United States exports [1] [2]	Total consumption of United States rice [1]
	Foreign and United States rice									Foreign rice	United States rice [1]		
	United States		Porto Rico		Hawaii [1]		Alaska		Total [1]				
	Total	Per capita	Total	Per capita	Total	Per capita	Total	Per capita					
	1,000 pockets [3]	*Pounds*	*1,000 pockets*	*Pounds*	*1,000 pockets*	*Pounds*	*1,000 pockets*	*Pounds*	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*
1918–19	5,829	5.7	1,669	114.8	433	181.2	16	----------	7,947	438	7,509	2,191	9,700
1919–20	3,632	3.4	1,405	98.6	438	175.0	14	----------	5,489	691	4,798	4,745	9,543
1920–21	5,565	5.2	1,648	113.7	521	199.2	8	----------	7,742	476	7,266	4,863	12,129
1921–22	4,890	4.5	1,643	113.3	472	173.0	11	19.8	7,016	198	6,818	4,740	11,558
1922–23	5,848	5.3	1,702	117.4	562	198.0	14	----------	8,126	315	7,811	3,249	11,060
1923–24	5,890	5.3	1,824	123.3	608	205.9	13	----------	8,335	354	7,981	1,564	9,545
1924–25	6,192	5.5	1,778	118.6	659	215.0	12	----------	8,641	435	8,206	744	8,950
1925–26	6,060	5.3	1,860	124.0	658	207.1	13	----------	8,591	909	7,682	285	7,967
1926–27	6,671	5.7	1,833	122.2	696	211.6	11	----------	9,211	464	8,747	2,381	11,128
1927–28	7,370	6.2	1,932	132.9	704	206.9	13	----------	10,019	327	9,692	2,390	12,082
1928–29	7,017	5.8	2,084	141.5	814	231.6	13	----------	9,928	237	9,691	3,196	12,887
1929–30	6,495	5.3	1,941	125.7	832	229.4	13	21.9	9,281	271	9,010	2,244	11,254

Compiled from annual reports of the Rice Millers' Association, New Orleans, except as otherwise stated.

[1] Hawaiian production not included. University of Hawaii reports Hawaiian production, in terms of cleaned rice, for Hawaii as follows: 1919, 15,000,000 pounds; 1924, 24,000,000 pounds; 1927, 17,000,000 pounds.

[2] Compiled from Monthly Summaries of Foreign and Domestic Commerce.

[3] A pocket of cleaned rice weighs 100 pounds.

TABLE 11.—*United States exports of grain rice by countries, expressed as percentage of total exports, 1921–22 to 1929–30*

[Year beginning August 1]

Country of destination	1921–22	1922–23	1923–24	1924–25	1925–26	1926–27	1927–28	1928–29	1929–30
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Germany	12.29	5.69	3.76	5.15	11.99	15.74	15.09	14.44	16.09
United Kingdom	7.12	11.01	15.81	14.97	28.98	14.11	15.23	13.47	15.17
Argentina	1.28	5.10	2.12	14.37	8.17	5.38	5.43	11.82	11.73
Belgium	5.68	8.97	8.01	11.27	9.11	7.97	5.66	6.94	4.16
Canada	3.42	5.50	12.03	8.80	3.62	3.17	6.17	6.38	7.70
Netherlands	4.65	5.57	9.10	2.24	2.29	8.61	10.23	6.13	6.45
Colombia	.76	.96	.39	1.00	1.58	.31	3.97	5.95	8.46
France	5.74	8.82	3.37	4.58	.95	2.23	5.28	5.15	5.96
Chili	3.73	6.76	3.86	6.91	2.01	4.23	6.29	4.85	7.96
Cuba	8.37	3.82	.88	1.70	10.55	2.24	11.69	4.82	2.78
Japan	29.23	20.21	27.55	.67	2.25	27.18	.72	4.55	.42
Others [1]	17.73	17.59	13.12	28.34	18.50	8.83	14.24	15.50	13.12
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Compiled from Foreign Commerce and Navigation of the United States and Monthly Summaries of Foreign Commerce of the United States.

[1] The number of countries included in "Others" averaged 52 during the period 1921–22 to 1929–30.

TABLE 12.—*United States exports of table grades of rice through San Francisco, by months, 1919–20 to 1930–31* [1]

Month	1919–20		1920–21		1921–22		1922–23	
	To Japan	Total	To Japan	Total	To Japan	Total	To Japan	Total
	1,000 pounds	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*
October	0	1,160	(2)	(2)	16,746	17,886	5	489
November	0	2,155	(2)	(2)	14,736	15,667	305	970
December	0	18,289	(2)	(2)	17,578	18,989	30	873
January	(2)	(2)	0	10,196	4,108	5,283	1	1,234
February	(2)	(2)	0	235	7,078	8,158	0	514
March	(2)	(2)	0	1,094	15,651	16,713	34	905
April	(2)	(2)	0	999	7,690	9,004	355	1,206
May	(2)	(2)	0	1,266	6,215	7,240	2,225	3,763
June	(2)	(2)	543	5,560	15,700	17,585	8,652	9,638
July	(2)	(2)	738	10,732	22,520	23,908	22,149	23,038
August	(2)	(2)	2,094	7,648	14,852	15,390	2,804	3,904
September	(2)	(2)	3,601	10,346	4,525	4,778	17,237	18,380
Total		21,604	6,976	48,076	147,399	160,601	53,797	64,914

Month	1923–24		1924–25		1925–26		1926–27	
	To Japan	Total	To Japan	Total	To Japan	Total	To Japan	Total
	1,000 pounds	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*
October	1,661	2,145	58	580	0	2	802	909
November	325	868	336	1,751	55	183	1,583	2,103
December	4,689	5,375	1,161	1,180	94	318	880	1,657
January	4,751	5,722	0	80	0	16	10	204
February	1,200	1,927	0	200	0	72	12,083	12,669
March	3,622	4,383	2,389	2,489	87	170	13,190	14,173
April	310	1,379	0	37	0	174	23,070	23,390
May	700	1,417	0	36	0	320	9,790	10,346
June	0	1,039	0	13	0	228	4,099	4,620
July	63	534	0	1	209	321	100	354
August	0	333	150	195	230	264	60	239
September	0	342	50	53	428	447	0	365
Total	17,321	25,464	4,144	6,615	1,103	2,515	65,667	71,029

[1] Includes rice meal and broken rice prior to Jan. 1, 1922.
[2] Not available.

TABLE 12.—*United States exports of table grades of rice through San Francisco, by months, 1919–20 to 1930–31*—Continued

Month	1927–28		1928–29		1929–30		1930–31	
	To Japan	Total	To Japan	Total	To Japan	Total	To Japan	Total
	1,000 pounds	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*
October	0	603	2	1,037	0	276	0	625
November	19	721	30	1,771	182	484	3	1,198
December	50	280	375	5,187	100	419	0	20
January	70	279	63	8,414	0	442	0	418
February	614	982	0	7,988	127	789	0	493
March	100	1,185	5,908	13,170	100	1,374	0	2,038
April	300	1,136	5,300	14,912	0	878		
May	275	1,299	530	12,120	0	1,194		
June	430	1,322	187	5,099	0	1,491		
July	60	3,198	0	5,264	0	552		
August	0	405	0	3,318	160	650		
September	2,154	2,768	426	1,521	650	872		
Total	4,072	14,178	12,821	79,801	1,319	9,421		

Compiled from Monthly Summary of Foreign Commerce of the United States.

TABLE 13.—*United States exports of grain rice through stated ports, by country of destination, 1925–26 to 1929–30*

[Year beginning August 1]

Country to which exported	Gulf ports [1]					San Francisco					All ports				
	1925–26	1926–27	1927–28	1928–29	1929–30	1925–26	1926–27	1927–28	1928–29	1929–30	1925–26	1926–27	1927–28	1928–29	1929–30
	1,000 pounds	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*
Belgium	2,592	19,289	13,519	19,638	9,338		78		2,534		2,617	19,368	13,520	22,185	9,338
Germany	3,079	36,890	35,212	42,616	34,802	242	496	686	3,535	1,254	3,201	37,386	36,018	46,150	36,102
Netherlands	612	17,501	24,332	19,302	14,428	22	74	89	258	39	634	17,574	24,421	19,588	14,467
United Kingdom	7,813	33,481	34,412	32,658	32,724	512	776	1,942	10,365	1,322	8,324	34,288	36,357	43,066	34,046
Canada						265	3,073	3,932	6,383	6,184	1,039	7,706	14,724	20,389	17,275
Honduras	1,559	2,578	3,358	3,413	2,991		4		4		1,559	2,632	3,358	3,421	2,993
Cuba	2,990	4,824	27,622	11,840	6,233			170	3,489		3,031	4,973	27,908	15,398	6,234
Argentina	2,345	13,051	12,975	15,616	24,284				22,163	1,360	2,345	13,075	12,974	37,780	26,316
Chile	576	10,243	14,992	13,920	17,785		12		1,578		578	10,265	15,013	15,499	17,870
Colombia	261	578	9,339	18,816	18,926		27	12	4	75	261	578	8,883	19,015	18,985
Japan						645	66,265	1,978	14,549	935	645	66,269	1,980	14,549	935
Other countries	2,424	20,659	37,894	46,220	36,888	366	331	2,800	13,273	1,568	4,219	23,950	43,843	62,597	39,803
Total	24,251	159,094	213,655	224,039	198,399	2,052	71,136	11,609	78,135	12,737	28,453	238,064	238,999	319,637	224,364

Compiled from records of the Bureau of Foreign and Domestic Commerce.

[1] Includes Galveston, Sabine, and New Orleans customs districts.

TABLE 14.—*Rice production, net inshipments, and consumption in Japan, 1900–1931*

Calendar year	Production [1]	Net inshipments [2]	Consumption		Calendar year	Production [1]	Net inshipments [2]	Consumption	
			Total	Per capita				Total	Per capita
	1,000,000 pounds	*1,000,000 pounds*	*1,000,000 pounds*	*Pounds*		*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*	*Pounds*
1900	12,471	233	12,704	290	1916	17,569	483	18,186	339
1901	13,027	290	13,317	300	1917	18,363	450	19,232	354
1902	14,738	245	14,983	333	1918	17,143	1,904	19,711	359
1903	11,602	1,646	13,248	291	1919	17,184	2,883	19,503	353
1904	14,600	1,728	16,328	354	1920	19,107	893	19,577	351
1905	16,157	1,690	17,847	383	1921	19,857	1,406	20,429	363
1906	11,992	1,028	13,020	276	1922	17,335	2,147	19,751	346
1907	14,546	935	15,481	325	1923	19,067	1,732	20,962	362
1908	15,410	910	16,320	338	1924	17,418	2,754	20,668	352
1909	16,315	675	16,990	348	1925	17,960	3,198	21,067	355
1910	16,474	366	16,840	340	1926	18,756	2,828	21,437	356
1911	14,650	783	15,433	308	1927	17,465	3,577	21,105	346
1912	16,246	820	17,066	336	1928	19,510	[3]	[3]	[3]
1913	15,778	1,345	17,123	332	1929	18,945	[3]	[3]	[3]
1914	15,789	1,233	16,126	308	1930	18,709	[3]	[3]	[3]
1915	17,909	723	18,510	349	1931	20,516	[3]	[3]	[3]

Compiled as follows: 1900–1927, Census of Rice Production, Department of Agriculture and Commerce Japan; 1928–1929, Statistical Abstract of the Ministry of Agriculture and Forestry, Japan; 1930–1931, Japanese Financial and Economic Monthly, November 1930. (Carry-over included 1914–1927; not available prior to 1914.)

[1] Harvested November and December of previous year.
[2] Inshipments include imports and inshipments from colonial possessions.
[3] Not available.

TABLE 15.—*Production in terms of cleaned rice in specified Asiatic countries, 1900–1901 to 1930–31*

Year beginning Nov. 1	Japan	Chosen	Taiwan	Total Japanese Empire [1]	India	French Indo-China	Siam	Total India, French, Indo-China, and Siam
	1,000,000 pounds	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*
1900–1901	13,027	[2] 3,200	1,351	17,578	46,313	[3] 5,000	[3] 2,500	53,813
1901–2	14,738	[2] 3,200	963	18,901	43,041	[3] 5,000	[3] 2,500	50,541
1902–3	11,602	[2] 3,200	886	15,688	52,582	[3] 5,000	2,650	60,232
1903–4	14,600	[2] 3,200	1,155	18,955	49,199	[3] 5,000	3,099	57,298
1904–5	16,157	[2] 3,200	1,307	20,664	50,228	[3] 5,000	3,137	58,365
1905–6	11,992	[2] 3,200	1,368	16,560	48,512	[3] 5,000	3,368	56,880
1906–7	14,546	[2] 3,200	1,247	18,993	47,907	[3] 5,000	2,973	55,880
1907–8	15,410	[2] 3,200	1,418	20,028	42,598	[3] 5,000	3,449	51,047
1908–9	16,315	[2] 3,200	1,463	20,978	43,877	[3] 5,000	3,385	52,262

Compiled as follows:
Japan: 1900–1908, Thirty-fifth Statistical Report of the Department of Agriculture and Commerce. Japan, 1918, p. 8; 1909, The Agricultural and Commerical Statistics for 1919, Japan; 1910, The Agricultural and Commercial Statistics for 1920; 1911–12, The Agricultural and Commercial Statistics for 1921; 1913–14, The Statistics of Agriculture, Industries, and Commerce, 1922, Japan; 1915–1924, The Statistical Abstract of the Ministry of Agriculture and Forestry, 1927, Japan; 1925–1928, The Statistical Abstract of the Ministry of Agriculture and Forestry, 1929, Japan; 1929 and 1930, Japanese Financial and Economic Monthly, November, 1930.
Chosen: 1909, Thirty-fifth Statistical Report of the Department of Agriculture and Commerce, Japan (1918); 1910, The Agriculture and Commerical Statistics for 1920 (Japan); 1911–1916, The Agriculture and Commerical Statistics for 1921 (Japan); 1917–1920, area, The Agriculture and Commerical Statistics for 1921. (Japan) production, A report from Consul General R. S. Miller, Seoul, Chosen, dated Nov. 10, 1924; 1921–1929, Reports from Consul General R. S. Miller, Seoul, Chosen, dated Oct. 7, 1926; Oct. 11, 1927; Oct. 3, 1928; Feb. 11, 1929; Feb. 21, 1929; Oct. 12, 1929; and Feb. 11, 1931.
Taiwan: 1900–1908, The Statistical Report of the Department of Agriculture and Commerce, Japan, No. 26–34; 1909–1927, Résumé Statistique de L'Empire du Japon, 1921–1930; 1928–29, International Yearbook of Agricultural Statistics; 1930, International Review of Agriculture, Pt. III, Monthly Crop Report, January, 1931.
Siam: Statistical Yearbook of the Kingdom of Siam, 1924 to 1928–29; Siam Record, July, 1930.
French Indo-China: International Yearbook of Agricultural Statistics.
India: 1900–1926, Area and Yield; 1927–1930, Indian Trade Journal, Feb. 28, 1929; Feb. 27, 1930; Feb. 26, 1931.

[1] Including production of Chosen prior to the time it became a part of the Japanese Empire.
[2] Estimated from official returns of exports of Chosen and from per capita consumption of rice in Japan 1804–1903, including food, seed and waste, but not including rice used for saké (270 pounds per annum).
[3] Estimated from exports.

TABLE 15.—*Production in terms of cleaned rice in specified Asiatic countries 1900–1901 to 1930–31*—Continued

Year beginning Nov. 1	Japan	Chosen	Taiwan	Total Japanese Empire [1]	India	French Indo-China	Siam	Total India, French, Indo-China, and Siam
	1,000,000 pounds	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*
1909–10	6,474	2,343	1,455	20,272	63,869	[3] 5,000	3,734	72,603
1910–11	14,650	3,269	1,316	19,235	64,552	[3] 5,000	3,466	73,018
1911–12	16,246	3,634	1,410	21,290	63,943	[3] 5,000	4,533	73,476
1912–13	15,778	3,413	1,271	20,462	63,802	6,614	4,561	74,977
1913–14	15,789	3,804	1,610	21,203	64,555	8,051	4,994	77,600
1914–15	17,909	4,439	1,448	23,796	61,109	9,521	4,708	75,338
1915–16	17,569	4,036	1,504	23,109	73,315	7,921	4,786	86,022
1916–17	18,363	4,377	1,461	24,201	78,521	6,733	5,011	90,265
1917–18	17,143	4,261	1,519	22,923	80,559	6,313	5,133	92,005
1918–19	17,184	4,765	1,455	23,404	54,466	6,302	4,642	65,410
1919–20	19,107	3,974	1,547	24,628	71,734	6,532	3,114	81,380
1920–21	19,857	4,639	1,521	26,017	61,949	6,284	5,868	74,101
1921–22	17,335	4,500	1,563	23,398	74,240	7,931	5,806	87,977
1922–23	19,067	4,717	1,711	25,495	75,495	7,629	5,954	89,078
1923–24	17,418	4,767	1,529	23,714	63,164	7,206	6,034	76,404
1924–25	17,960	4,153	1,909	24,022	69,601	7,801	6,779	84,181
1925–26	18,756	4,641	2,024	25,421	68,851	7,951	5,752	82,554
1926–27	17,465	4,807	1,952	24,224	66,483	8,255	7,169	81,907
1927–28	19,510	5,435	2,167	27,112	63,244	8,833	6,261	78,338
1928–29	18,945	4,245	2,135	25,325	71,989	7,826	5,325	85,140
1929–30	18,709	4,304	2,036	25,049	69,733	8,045	5,315	83,093
1930–31	20,516	6,026	2,371	28,913	70,771	[4]	[4]	[4]

[1] Including production of Chosen prior to the time it became a part of the Japanese Empire.
[3] Estimated from exports.
[4] Not available.

TABLE 16.—*Annual supply of rice for Japan, 1913–14 to 1930–31*

Year beginning Oct. 1	Carry-over	Production	Imports from—		Total supply
			Colonies	Foreign countries	
	1,000,000 pounds	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*
1913–14	942	15,789	565	785	18,081
1914–15	1,822	17,909	817	157	20,705
1915–16	1,948	17,569	660	94	20,271
1916–17	1,822	18,363	628	157	20,970
1917–18	1,414	17,143	911	1,162	20,630
1918–19	754	17,184	1,288	1,696	20,922
1919–20	1,319	19,107	723	220	21,369
1920–21	1,728	19,857	1,225	251	23,061
1921–22	2,576	17,335	1,225	1,194	22,330
1922–23	2,293	19,067	1,445	503	23,308
1923–24	2,136	17,418	1,979	1,037	22,570
1924–25	1,634	17,960	2,199	1,602	23,395
1925–26	1,728	18,756	2,325	660	23,469
1926–27	1,885	17,465	2,670	1,288	23,308
1927–28	1,791	19,510	3,047	848	25,196
1928–29	2,435	18,945			
1929–30	2,173	18,709			
1930–31		20,516			

Compiled as follows: 1913–14 to 1927–28, Reports of the Bureau of Agriculture, Department of Agriculture and Forestry, Imperial Government of Japan; carry-over, 1928–29 to 1929–30, James A. Anderson & Co., Rice Market Report, Dec. 6, 1929; production, 1928–29, The Statistical Abstract of the Ministry of Agriculture and Forestry, 1929, Japan; 1929–30, Japanese Financial and Economic Monthly, November, 1930.

TABLE 17.—*Rice stocks in Japan, May 1, July 1, and November 1, 1913–1930*

Year	May 1			July 1			Nov. 1		
	Japanese	Foreign	Total [1]	Japanese	Foreign	Total [1]	Japanese	Foreign	Total [1]
	1,000 pounds	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*
1913	7,022,498	293,542	7,353,852	4,599,033	418,325	5,053,942	939,813	[2]	[2]
1914	7,955,935	359,965	8,527,520	5,637,860	328,497	6,067,469	1,836,544	[2]	[2]
1915	9,221,100	69,712	9,398,747	6,904,928	49,545	7,031,405	1,958,769	[2]	[2]
1916	9,516,025	25,876	9,676,110	6,820,445	16,913	6,920,875	1,719,250	50,018	1,825,282
1917	9,483,362	23,062	9,631,176	6,384,031	42,759	6,482,908	1,270,889	50,682	1,405,668
1918	7,860,288	144,004	8,101,956	5,050,896	163,560	5,275,696	572,706	101,910	742,010
1919	7,655,360	493,000	8,278,177	5,051,921	475,645	5,605,406	867,791	365,019	1,307,147
1920	9,016,829	238,541	9,367,599	6,244,268	231,188	6,539,010	1,438,903	224,579	1,730,016
1921	10,348,498	247,605	10,743,304	7,250,080	244,839	7,625,630	2,211,742	203,714	2,563,914
1922	9,353,342	618,468	10,294,712	6,586,263	468,765	7,229,868	1,830,050	381,279	2,294,991
1923	9,863,294	157,993	10,260,687	6,890,942	160,950	7,289,998	1,718,566	313,025	2,133,069
1924	8,625,855	191,516	9,203,512	5,778,027	346,700	6,406,313	1,107,963	450,595	1,636,824
1925	8,547,337	471,005	9,252,572	5,673,127	572,251	6,423,140	1,132,582	507,837	1,727,865
1926	9,115,817	400,582	7,746,218	6,144,173	461,620	6,744,922	1,412,893	386,776	1,874,808
1927	8,610,887	451,513	9,401,256	5,797,603	475,727	6,518,449	1,346,704	340,053	1,799,480
1928	10,101,647	193,195	10,551,958	7,059,253	165,016	7,398,525	2,242,941	91,483	2,459,138
1929	10,056,230	68,410	10,442,264	7,135,889	67,804	7,431,930	[2]	[2]	[3] 3,203,865
1930				6,664,623	44,467	6,861,775			

Compiled from Rice Statistics, Department of Agriculture and Forestry, Imperial Government of Japan, 1913–1916 from issue of November, 1924; 1917–1926 from issue of November, 1928; 1927, 1928, 1930 from same source by press release from report to Commerce Department by Paul P. Steintorf, Trade Commissioner.

[1] Includes Taiwan and Chosen rice.
[2] No report.
[3] Estimate.

TABLE 18.—*Index numbers of prices and wages in Japan (Tokyo) and exchange rate of the yen, 1900–1930*

Calendar year	Index numbers of wholesale prices, all commodities [1] [2]	Index numbers of wholesale prices, all commodities [2]	Index numbers of wages [2]	Exchange rate per dollar	Calendar year	Index numbers of wholesale prices, all commodities [1] [2]	Index numbers of wholesale prices, all commodities [2]	Index numbers of wages [2]	Exchange rate per dollar
				Yen					*Yen*
1900	97	100	100		1916	182	155	137	1.999
1901	97	96	98	2.006	1917	238	194	168	1.978
1902	101	97	98	2.006	1918	289	254	215	1.947
1903	107	103	96	2.006	1919	364	312	302	1.973
1904	114	108	96	2.006	1920	266	343	423	2.010
1905	119	116	101	2.006	1921	266	265	421	2.079
1906	127	120	108	2.006	1922	256	259	446	2.086
1907	125	129	120	2.006	1923	272	263		2.051
1908	119	124	129	2.006	1924	272	273		2.555
1909	120	118	126	2.006	1925	245	267		2.451
1910	124	120	127	2.006	1926	226	237		2.134
1911	130	125	129	2.006	1927	225	225		2.109
1912	132	132	132	2.006	1928	224	226		2.155
1913	129	132	135	2.006	1929	223	220		2.169
1914	125	126	134	2.006	1930	189	181		2.025
1915	147	128	130	2.047					

Compiled as follows: 1900 to 1927, Report of the Bank of Japan as published in Census of Rice Statistics, Department of Agriculture and Commerce, Japan; 1928–1930, Federal Reserve Bulletins, 1929 and 1931.

[1] For crop year beginning Nov. 1 of previous year.
[2] October, 1900=100.

TABLE 19.—*Price differential, Tokyo and San Francisco, Japanese import duty, and California exports to Japan of brown rice, by months, 1921–1926*

Year and month	Price differential per pound	Japanese import duty per pound	California exports to Japan	Year and month	Price differential per pound	Japanese import duty per pound	California exports to Japan
1921	*Cents*	*Cents*	*1,000 pounds*	1924	*Cents*	*Cents*	*1,000 pounds*
January	0.52	0.38		January	.38	[2]	4,751
February	[1]—.20	.38		February	.48	[2]	1,200
March	[1]—.40	.38		March	.46	[2]	3,622
April	[1]—.05	.38		April	.57	[2]	310
May	.15	.38		May	.55	[2]	700
June	.47	.38	543	June	.55	[2]	
July	.52	.38	738	July	.52	[2]	63
August	.93	.38	2,094	August	.60	.32	
September	1.43	.38	3,601	September	.57	.32	
October	1.81	.38	16,746	October	.56	.32	58
November	1.77	.38	14,736	November	[3]	.32	336
December	1.50	[2]	17,578	December		.32	
1922				1925			
January	1.29	[2]	4,108	January	[3]	[2]	70
February	1.22	[2]	7,078	February		[2]	614
March	1.12	[2]	15,651	March		[2]	100
April	1.13	[2]	7,690	April		[2]	300
May	1.01	[2]	6,215	May		[2]	275
June	1.35	[2]	15,700	June		[2]	430
July	1.21	[2]	22,520	July		[2]	60
August	1.06	[2]	14,852	August		[2]	0
September	.71	[2]	4,525	September		[2]	2,154
October	.61	[2]	5	October		[2]	2
November	.50	.38	305	November		.31	30
December	.21	.38	30	December		.31	375
1923				1926			
January	.36	.38	1	January		.31	
February	.85	.38		February		.31	
March	.82	.38	33	March		[3]	
April	1.02	.38	355	April		[2]	
May	1.17	.38	5,225	May		[2]	
June	1.41	.38	8,652	June		[2]	
July	1.27	.38	22,149	July		[2]	
August	1.28	.38	2,804	August		.33	
September		[2]	1,837	September		.33	
October		[2]	8,584	October		[2]	
November	1.05	[2]	324	November		[2]	
December	1.03	[2]	4,690	December		[2]	

Compiled from Rice Statistics, Department of Agriculture and Commerce, Imperial Government of Japan.

[1] Tokyo price was below San Francisco.
[2] No import duty.
[3] No quotations on San Francisco Exchange until March, 1927.

TABLE 20.—*Price per pound of California, Japan, and Rangoon types of brown rice on Kobe exchange, by months, 1923–1927*

Year and month	California	Japan	Rangoon	Year and month	California	Japan	Rangoon
1923	*Cents*	*Cents*	*Cents*	1924	*Cents*	*Cents*	*Cents*
January	3.89	4.62	2.65	March	5.30	5.86	3.34
February	3.70	4.79	2.98	April	5.99	5.90	3.62
March	3.70	4.89	3.09	May	5.51	5.88	3.67
April	3.96	4.97	3.13	June	5.51	5.98	3.64
May	4.50	5.26	3.34	July	[1]	6.10	3.58
June	4.86	5.57	3.48	August	[1]	6.35	3.79
July	4.76	5.55	3.25	September	[1]	6.56	3.88
August	4.76	5.57	3.21	October	[1]	6.94	4.25
September	4.57	5.36	3.26	November	[1]	6.96	4.24
October	4.39	5.16	2.68	December	[1]	6.62	4.24
November	4.88	5.46	2.87				
December	5.09	5.41	2.99	1925			
				January	[1]	6.63	4.26
1924				February	[1]	6.57	4.29
January	5.38	5.92	3.47	March	[1]	6.58	4.05
February	5.44	5.89	3.53	April	[1]	6.70	3.88

TABLE 20.—*Price per pound of California, Japan, and Rangoon types of brown rice on Kobe exchange, by months, 1923–1927*—Continued

Year and month	California	Japan	Rangoon	Year and month	California	Japan	Rangoon
1925	*Cents*	*Cents*	*Cents*	1926	*Cents*	*Cents*	*Cents*
May	(1)	6.73	3.87	September	(1)	6.27	4.05
June	(1)	6.98	3.94	October	(1)	6.22	4.01
July	(1)	7.12	3.94	November	(1)	5.96	4.00
August	(1)	7.34	4.05	December	(1)	5.84	3.97
September	(1)	7.21	3.93				
October	(1)	7.04	3.99	1927			
November	(1)	6.21	4.01	January	(1)	5.84	3.72
December	(1)	5.91	3.94	February	(1)	5.77	3.71
				March	(1)	5.84	3.50
1926				April	5.24	5.93	3.14
January	(1)	6.10	4.21	May	5.29	6.02	3.28
February	(1)	6.12	4.15	June	5.28	5.99	3.31
March	(1)	6.09	4.17	July	5.23	6.05	3.26
April	(1)	6.10	4.15	August	4.81	5.93	3.32
May	(1)	6.08	4.09	September	4.40	6.34	3.38
June	(1)	6.22	4.12	October	(1)	5.92	3.36
July	(1)	6.40	4.16	November	(1)	5.61	3.26
August	(1)	6.40	4.11	December	(1)	5.06	3.23

Compiled from Rice Statistics, Department of Agriculture and Commerce, Imperial Government of Japan, 1924 and 1928, and converted at the par rate of exchange (2.006 yen=$1).

[1] No quotations.

TABLE 21.—*Rice imports into Japan by countries, 1919–1928*

Country	1919		1920		1921		1922		1923	
	Imports	Percentage of total imports	Imports	Percentage of total imports	Imports	Percentage of total imports	Imports	Percentage of total imports	Imports	Percentage of total imports
	1,000 lbs.	*Per cent*	*1,000 lbs.*	*Per cent*	*1,000 lbs.*	*Per cent*	*1,000 lbs.*	*Per cent*	*1,000 lbs.*	*Per cent*
China and Manchuria	114,769	7.87	12,305	8.31	4,563	0.91	5,978	0.63	8,214	1.48
British India	8,494	.58	2,869	1.94	38,329	7.65	241,163	25.22	127,959	23.02
French Indo-China	1,010,121	69.26	117,310	79.27	231,743	46.24	195,174	20.41	108,550	19.53
Siam	324,551	22.25	15,334	10.36	190,497	38.01	368,772	38.56	218,360	39.28
United States	0	0	156	.11	35,696	7.12	144,138	15.07	48,404	8.71
Others	495	.04	19	.01	369	.07	1,037	.11	44,428	7.98
Total	1,458,430	100.00	147,993	100.00	501,197	100.00	956,262	100.00	555,915	100.00

	1924		1925		1926		1927		1928	
China and Manchuria	37,711	3.67	31,480	1.95	9,317	1.29	32,649	2.67	2,910	0.52
British India	459,545	44.76	626,523	38.80	220,148	30.42	319,736	26.10	30,246	5.41
French Indo-China	204,854	19.95	583,021	36.10	267,125	36.91	382,558	31.23	187,042	33.44
Siam	282,152	27.48	350,155	21.68	200,757	27.74	378,685	30.91	333,202	59.58
United States	39,581	3.86	23,160	1.43	26,061	3.60	92,358	7.54	5,127	.92
Others	2,776	.28	599	.04	238	.04	18,944	1.55	732	.13
Total	1,026,619	100.00	1,614,938	100.00	723,646	100.00	1,224,930	100.00	559,259	100.00

Compiled from Rice Statistics, Department of Agriculture and Forestry, Imperial Government of Japan 1919–1922 from issue of November, 1924; 1923–1927 from issue of November, 1928; 1928 from Annual Return of the Foreign Trade of the Empire of Japan, 1928.

TABLE 22.—*Exports of grain rice from principal producing countries, 1922–1930*

Calendar year	Unites States	Burma to—		Saigon, French Indo-China	Siam
		India	Other countries		
	1,000 pounds	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*	*1,000 pounds*
1922	358, 827	1, 984, 649	4, 030, 578	2, 778, 621	2, 515, 635
1923	292, 852	1, 536, 799	3, 742, 912	2, 524, 961	3, 076, 574
1924	122, 543	1, 311, 502	4, 338, 219	2, 431, 026	2, 284, 553
1925	39, 907	2, 626, 118	5, 003, 654	3, 144, 580	2, 955, 050
1926	77, 081	1, 623 935	4, 868, 208	3, 036, 094	2, 790, 534
1927	239, 596	[1] 2, 208, 042	4, 996, 085	3, 235, 830	3, 806, 293
1928	288, 702	[1] 2, 661, 048	3, 968, 180	3, 673, 221	3, 404, 779
1929	315, 441	[1] 1, 993, 011	4, 594, 430	2, 770, 933	2, 588, 033
1930	213, 066	[1] 1, 727, 040	5, 815, 040	2, 333, 371	2, 307, 263

Compiled as follows: United States, Foreign Commerce and Navigation of the United States, and Monthly Summary of Foreign and Domestic Commerce; Burma, Saigon, and Siam, 1922–1926 from Annual Statistics of Rice, Department of Agriculture and Forestry, Japan; Burma, 1927–1930, Weekly Rice Report, Lockie, Pemberton & Co., Jan. 10, 1931; Saigon, 1927–1930, issues of Bulletin Bi-Mensuel de la Chambre de Commerce de Saigon; Siam, 1927, 1928, Statistical Yearbook of the Kingdom of Siam, 1926–27, 1928–29; Siam, 1929, The Record, Ministry of Commerce and Communications, Bangkok, Siam; Siam, 1930, Weekly Report, Lockie, Pemberton & Co., Feb. 14, 1931.

[1] From Rangoon.

TABLE 23.—*Rice exports from Burma, Saigon, and Siam, by countries of destination, expressed as percentages of total exports, 1921–1930*

BURMA [1]

Country of destination	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Germany	18. 95	19. 08	22. 80	20. 81	16. 37	[2] 20. 65	[2] 18, 76	[2] 22. 57	[2] 22. 50	[2] 17. 18
England	8. 80	4. 04	3. 12	4. 63	3. 53	-------	-------	-------	-------	-------
Ceylon	20. 82	16. 27	10. 75	10. 45	15. 05	-------	-------	-------	-------	-------
Straits Settlements	11. 15	9. 70	13. 49	13. 25	11. 34	[3] 23. 25	[3] 15. 73	[3] 11. 13	[3] 15. 04	[3] 35. 79
Egypt	2. 81	5. 30	2. 24	4. 35	3. 11	[4] 3. 23	[4] 3. 69	[4] 3. 24	[4] 3. 61	[4] 2. 08
Java	10. 97	4. 26	7. 54	2. 41	4. 97	7. 91	5. 77	4. 90	9. 97	9. 75
Japan	3. 47	4. 47	7. 21	12. 02	12. 50	9. 00	9. 94	2. 26	4. 01	. 58
Others	23. 03	36. 88	32. 85	32. 08	33. 13	35. 96	46 11	55 90	44 87	34. 62
Total	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00

SAIGON (FRENCH INDO-CHINA)

France	8. 54	11. 97	18. 94	11. 68	13. 39	13. 74	14. 31	15. 45	14. 96	19. 24
Europe (other)	-------	5. 10	2. 41	1. 48	6. 44	3. 26	8. 78	10. 89	7. 79	2. 54
Hong Kong	45. 14	48. 12	59. 85	54. 97	35. 34	50. 01	[5] 50. 62	[5] 32. 84	[5] 35. 32	[5] 47. 36
Japan	6. 09	3. 83	2. 94	6. 98	17. 53	12. 45	12. 83	6. 59	3. 76	3. 17
Philippine Islands	. 96	3. 19	4. 28	11. 02	5. 92	4. 51	. 30	2. 98	7. 16	-------
Cuba	1. 06	5. 34	4. 06	2. 75	1. 62	1. 29	2. 38	2. 87	1. 98	1. 59
Java	21. 92	14. 82	2. 96	6. 57	11. 53	7. 15	3. 66	9. 04	15. 21	10. 62
Singapore	7. 38	5. 78	2. 47	3. 57	3. 52	5. 32	4. 92	5. 05	7. 90	8. 29
Others	8. 91	1. 85	2. 09	. 98	4. 71	2. 27	2. 20	14. 29	5. 92	7. 19
Total	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00

SIAM

Hong Kong	28. 37	50. 22	54. 09	45. 12	30. 61	21. 58	33. 17	32. 80	[6]	[6]
Japan	8. 71	2. 24	2. 67	3. 86	5. 48	8. 97	7. 39	2. 97	8. 99	10. 61
Port Said	11. 49	1. 22	1. 31	1. 21	. 58	. 34	-------	2. 31	-------	-------
Singapore	31. 75	30. 41	29. 19	30. 93	33. 77	41. 56	37. 79	39. 56	[3] 73. 80	[3] 71. 60
United Kingdom	4. 08	1. 59	. 08	1. 12	. 42	. 54	1. 96	7. 38	[2] 2. 52	[2] 2. 92
Others	15. 60	14. 32	12. 66	17. 76	29. 14	27. 01	19. 69	14. 98	14. 69	14. 87
Total	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00

Compiled as follows: Burma, 1921–1925; Saigon, 1921–1925; Siam, 1921–1925, from Rice Statistics, Department of Agriculture and Forestry, Japan; Burma, 1926–1930, Weekly Rice Report, Lockie, Pemberton & Co., Jan. 10, 1931; Saigon, 1927–1930, issues of Bulletin Bi-Mensuel de la Chambre de Commerce de Saigon; Siam, 1926–1928, Statistical Year Book of the Kingdom of Siam, 1928–29; Siam, 1929–30, Weekly Report; Lockie, Pemberton & Co., Feb. 14, 1931.

[1] Exports 1926–1930 were from Rangoon.
[2] Exports 1926–1930 were to Europe.
[3] Exports 1926–1930 were to Straits Settlements and China.
[4] Exports 1926–1930 were to African ports.
[5] Shanghai and other Chinese ports included.
[6] No report.

TABLE 24.—*Average wholesale price per 100 pounds of Fancy Blue Rose clean rice, at New Orleans, by months, 1920–21 to 1929–30*

Year beginning Aug. 1	August	September	October	November	December	January	February	March
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
1920–21	7.25	6.25	5.38	4.62	3.44	3.00	2.50	2.38
1921–22	3.19	3.50	3.78	3.69	3.12	3.10	3.18	3.44
1922–23	4.10	4.25	3.62	3.82	4.00	4.06	3.94	3.91
1923–24	3.78	4.00	4.88	4.66	4.38	4.62	4.69	5.06
1924–25	5.88	5.69	5.12	5.50	6.10	6.30	6.50	6.38
1925–26	6.62	6.31	5.69	6.34	6.41	6.31	6.59	6.25
1926–27	4.94	5.62	4.81	4.44	4.38	4.50	4.19	4.34
1927–28	4.12	4.12	3.84	3.62	3.69	3.75	3.66	3.62
1928–29	4.12	4.00	3.91	3.81	3.94	4.12	3.88	3.88
1929–30	4.25	4.03	3.78	3.88	3.84	3.97	4.12	4.38

Year beginning Aug. 1	April	May	June	July	Average			
					August–July	November–July	December–April	May–July
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
1920–21	2.25	2.40	2.56	3.06	3.76	2.91	2.71	2.67
1921–22	3.56	3.60	4.31	4.38	3.57	3.60	3.28	4.10
1922–23	4.00	3.56	3.75	3.94	3.91	3.89	3.98	3.75
1923–24	5.06	5.88	6.12	6.19	4.94	5.18	4.76	6.06
1924–25	6.34	6.50	6.81	6.88	6.17	6.37	6.32	6.73
1925–26	6.19	5.60	5.94	5.94	6.18	6.17	6.35	5.83
1926–27	4.06	4.12	4.52	4.22	4.51	4.31	4.29	4.29
1927–28	3.50	4.12	4.28	4.12	3.87	3.82	3.64	4.17
1928–29	3.88	3.75	3.81	3.81	3.91	3.88	3.94	3.79
1929–30	4.38	4.38	4.52	4.38	4.16	4.21	4.14	4.43

Compiled from annual reports of the New Orleans Board of Trade.

TABLE 25.—*Average wholesale price per 100 pounds of Fancy Blue Rose clean rice, at New Orleans; deflated by Bureau of Labor all-commodity price index, by months, 1920–21 to 1929–30* [1]

Year beginning August 1	August	September	October	November	December	January	February	March
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
1920–21	4.49	4.03	3.73	3.46	2.85	2.63	2.38	2.32
1921–22	3.41	3.75	4.02	3.92	3.36	3.39	3.42	3.71
1922–23	4.16	4.28	3.63	3.80	3.97	3.98	3.81	3.74
1923–24	3.87	4.01	4.91	4.74	4.46	4.64	4.70	5.14
1924–25	6.06	5.86	5.21	5.55	6.01	6.12	6.25	6.12
1925–26	6.37	6.10	5.49	6.07	6.20	6.09	6.45	6.23
1926–27	4.99	5.64	4.84	4.51	4.47	4.66	4.37	4.59
1927–28	4.33	4.27	3.96	3.74	3.81	3.89	3.80	3.77
1928–29	4.17	4.00	4.00	3.94	4.07	4.24	4.01	3.98
1929–30	4.35	4.13	3.93	4.11	3.98	4.25	4.47	4.82

Year beginning August 1	April	May	June	July	Average [2]			
					August–July	November–July	December–April	May–July
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
1920–21	2.28	2.49	2.74	3.28	3.06	2.72	2.49	2.84
1921–22	3.82	3.75	4.48	4.41	3.79	3.80	3.54	4.21
1922–23	3.85	3.49	3.74	4.00	3.87	3.82	3.87	3.75
1923–24	5.20	6.13	6.45	6.47	5.06	5.33	4.83	6.35
1924–25	6.22	6.40	6.61	6.60	6.08	6.21	6.14	6.54
1925–26	6.18	5.57	5.91	5.97	6.05	6.07	6.23	5.82
1926–27	4.33	4.40	4.82	4.48	4.68	4.52	4.48	4.57
1927–28	3.59	4.18	4.39	4.19	3.99	3.93	3.77	4.25
1928–29	4.01	3.91	3.95	3.89	4.01	4.00	4.06	3.92
1929–30	4.83	4.92	5.21	5.21	4.52	4.64	4.47	5.11

Compiled from annual reports of the New Orleans Board of Trade.

[1] 1926=100.

[2] Averages do not always agree with an average of figures given because the deflated figures were carried three decimal places before averaging.

TABLE 26.—*Production, carry-over, and total supply of milled rice, southern belt and California, 1914–15 to 1930–31*

Year beginning August 1	Southern belt [1]			California		
	Production	Carry-over	Total supply	Production	Carry-over	Total supply
	1,000,000 pounds	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*	*1,000,000 pounds*
1914–15	635	11	646	22	----------	22
1915–16	741	34	775	63	----------	63
1916–17	1,040	36	1,076	95	----------	95
1917–18	808	16	824	157	----------	157
1918–19	868	1	869	204	----------	204
1919–20	908	17	925	258	----------	258
1920–21	1,217	53	1,270	229	8	237
1921–22	842	89	931	203	97	300
1922–23	936	55	991	214	35	249
1923–24	779	80	859	158	56	214
1924–25	774	20	794	121	28	149
1925–26	791	9	800	133	7	140
1926–27	958	77	1,035	222	13	235
1927–28	994	108	1,102	249	7	256
1928–29	980	84	1,064	227	87	314
1929–30	951	49	1,000	173	68	241
1930–31	947	49	996	202	32	234

Compiled as follows: Production estimates from records of the Division of Crop and Live stock Estimates and carry-over from the annual report of the Rice Millers' Association.

[1] United States except California.

TABLE 27.—*Visible stocks of rough and cleaned rice in mills in the United States on first of each month, 1914–15 to 1929–30* [1]

Year beginning August 1	August 1	September 1	October 1	November 1	December 1	January 1	February 1	March 1	April 1	May 1	June 1	July 1
	1,000 barrels	*1,000 barrels*	*1,000 barrels*	*1,000 barrels*	*1,000 barrels*	*1,000 barrels*	*1,000 barrels*	*1,000 barrels*	*1,000 barrels*	*1,000 barrels*	*1,000 barrels*	*1,000 barrels*
1914–15	----------	362	790	1,065	1,176	1,097	1,122	938	771	625	453	341
1915–16	341	287	446	797	1,506	1,458	1,555	1,549	1,252	837	583	475
1916–17	356	343	612	1,156	1,767	1,772	1,412	1,390	1,218	785	335	209
1917–18	160	171	459	1,126	1,708	1,495	1,521	980	870	562	151	87
1918–19	57	99	657	883	1,075	1,302	1,107	1,098	1,014	965	578	309
1919–20	166	168	552	884	1,419	1,479	1,593	1,721	1,483	1,037	900	676
1920–21	526	533	748	966	2,338	2,922	2,431	1,936	1,601	1,593	1,493	1,059
1921–22	650	697	686	968	1,129	1,258	1,505	1,653	1,540	1,336	972	761
1922–23	515	402	621	1,410	2,003	2,326	2,284	2,039	1,743	1,575	1,170	966
1923–24	744	548	355	954	1,734	2,011	2,019	1,680	1,182	718	430	303
1924–25	165	399	638	1,567	2,265	2,347	1,867	1,560	1,060	674	364	223
1925–26	95	398	632	752	1,091	2,046	2,168	2,052	1,825	1,556	1,174	975
1926–27	767	716	1,218	1,879	2,197	2,362	2,096	1,958	1,868	1,697	1,401	1,181
1927–28	987	1,236	1,581	2,247	2,410	2,291	2,106	2,038	2,138	1,958	1,455	1,067
1928–29	830	696	1,108	1,142	2,887	2,792	2,515	2,315	2,058	1,764	1,311	865
1929–30	485	507	1,099	1,175	2,551	2,439	2,317	2,360	1,899	1,394	1,000	730

Compiled from monthly report of the Rice Millers' Association.

[1] Expressed in terms of rough rice. The conversion factor, 100 pounds of cleaned rice equivalent to 1 barrel (162 pounds) of rough rice, was used to convert the cleaned portion of visible rice stocks.

TABLE 28.—*Disappearance of United States rice in Southern States, by months, 1914–15 to 1929–30*

Year beginning Aug. 1	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Total
	1,000 pockets	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*	*1,000 pockets*
1914–15	504	332	571	896	875	723	559	416	277	185	232	124	5,694
1915–16	255	599	848	859	672	709	668	748	555	336	120	128	6,497
1916–17	334	620	1,205	1,374	1,036	964	725	1,312	726	499	138	68	9,001
1917–18	151	449	964	1,010	708	683	1,219	1,078	596	521	111	199	7,689
1918–19	104	532	1,091	1,037	1,224	1,249	413	380	355	560	332	144	7,421
1919–20	147	550	1,007	999	1,203	915	306	518	680	342	371	214	7,252
1920–21	242	610	963	901	593	1,122	1,210	1,037	1,037	1,420	787	839	10,761
1921–22	910	752	871	744	759	864	1,020	1,198	499	482	283	267	8,649
1922–23	520	790	1,425	1,287	940	1,015	562	654	708	560	348	345	9,154
1923–24	410	618	969	1,236	820	1,105	926	819	470	306	135	135	7,949
1924–25	131	730	1,303	1,300	933	981	543	496	390	337	192	140	7,476
1925–26	315	619	842	835	751	911	609	498	471	474	351	279	6,955
1926–27	310	717	1,035	1,007	895	1,120	877	734	569	700	643	345	8,952
1927–28	423	850	1,200	1,163	1,006	1,118	961	905	836	910	531	285	10,188
1928–29	346	777	1,246	1,278	1,053	973	816	766	745	715	650	515	9,880
1929–30	507	841	1,376	1,134	1,023	1,073	1,005	793	686	566	369	334	9,707

Compiled from monthly report of the Rice Millers' Association. A pocket of cleaned rice equals 100 pounds.

TABLE 29.—*Average wholesale and export price per 100 pounds of rice in selected countries, and index numbers of price in India, 1851–1930*

Calendar year	Average wholesale price in—				Export price in France	Index numbers of price in India [1]
	Hamburg	New York	London	Tokyo		
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	
1851	2.90	3.78	1.70			
1852	2.50	3.78	2.00			
1853	3.40	4.59	2.30			
1854	3.10	4.86	2.70			
1855	3.50	4.86	2.80			
1856	2.70	5.94	2.20			
1857	2.70	4.72	2.20			
1858	2.20	4.05	1.60			
1859	2.40	4.05	1.80			
1860	2.60	4.59	2.20			
1861	2.70	4.19	2.30		3.30	83.0
1862	2.50	8.37	2.30		3.20	79.9
1863	2.50	[2]	2.40		3.20	74.0
1864	2.50	[2]	2.10		2.60	101.5
1865	2.70	12.96	2.30		2.60	124.0
1866	2.50	12.96	2.60		3.10	180.0
1867	2.60	9.58	2.60		3.20	127.0
1868	2.50	9.29	2.40	0.95	2.80	98.0
1869	2.10	9.45	2.10	1.43	2.80	118.0
1870	2.40	7.83	2.10	1.46	3.10	96.6
1871	2.40	7.83	2.10	.89	3.50	92.0
1872	2.50	9.45	2.20	.62	3.70	86.3
1873	2.20	8.91	2.10	.76	3.80	100.0
1874	2.50	9.18	2.20	1.16	3.10	137.6
1875	2.10	8.64	1.80	1.16	4.40	141.0
1876	2.10	7.69	2.00	.79	4.60	106.6
1877	2.30	7.02	2.20	.88	4.70	149.3
1878	2.40	7.02	2.20	1.03	4.70	165.3
1879	2.30	6.88	2.10	1.27	4.90	176.0
1880	2.10	8.10	2.00	1.72	4.90	130.3
1881	2.10	7.55	1.80	1.78	4.70	105.3
1882	1.90	7.55	1.60	1.42	4.60	100.0
1883	2.10	6.48	1.80	.99	4.80	119.6
1884	2.00	6.48	1.70	.82	4.80	140.0
1885	1.90	6.61	1.50	1.04	4.80	135.3
1886	1.80	5.81	1.40	.89	3.10	131.3
1887	1.80	4.99	1.50	.79	3.10	114.0
1888	1.80	4.99	1.50	.78	2.60	122.3
1889	1.90	5.54	1.60	.95	3.20	148.3

[1] 1873=100.
[2] No report.

TABLE 29.—*Average wholesale and export price per 100 pounds of rice in selected countries, and index numbers of price in India, 1851–1930*—Continued

Calendar year	Average wholesale price in—				Export price in France	Index numbers of price in India
	Hamburg	New York	London	Tokyo		
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	
1890	1.90	6.10	1.60	1.42	3.20	147.6
1891	2.00	6.40	1.70	1.12	3.20	148.0
1892	2.30	5.70	1.70	1.15	----------	172.3
1893	2.10	4.60	1.30	1.17	----------	171.3
1894	2.00	5.30	1.30	1.40	----------	166.0
1895	1.90	5.30	1.20	1.41	----------	140.0
1896	1.80	5.20	1.30	1.53	----------	154.0
1897	----------	5.40	1.50	1.90	----------	208.3
1898	----------	6.10	1.60	2.37	----------	164.3
1899	----------	6.10	1.60	1.59	----------	134.3
1900	----------	5.50	1.60	1.89	----------	146.6
1901	----------	5.50	1.40	1.95	----------	159.6
1902	----------	5.60	1.30	2.01	----------	166.6
1903	----------	5.70	1.60	2.29	----------	158.0
1904	----------	4.40	1.40	2.10	----------	150.6
1905	----------	4.20	1.50	2.04	----------	149.6
1906	----------	4.70	1.60	2.34	----------	202.3
1907	----------	5.30	1.80	2.62	----------	241.3
1908	----------	6.20	1.60	2.53	----------	250.0
1909	----------	6.20	1.50	2.09	----------	215.5
1910	----------	5.50	1.60	2.11	----------	155.6
1911	----------	5.00	1.80	2.75	----------	181.3
1912	----------	5.50	2.20	3.33	----------	184.0
1913	----------	5.50	1.80	3.38	----------	153.0
1914	----------	[2]	2.00	2.56	----------	216.6
1915	----------	4.00	2.80	2.07	----------	226.0
1916	----------	3.80	3.60	2.18	----------	221.5
1917	----------	6.30	5.40	3.15	----------	200.3
1918	----------	8.20	5.60	5.20	----------	136.0
1919	----------	9.80	5.10	7.30	----------	277.5
1920	----------	9.60	7.60	7.08	----------	340.0
1921	----------	3.30	3.20	4.89	----------	----------
1922	----------	4.40	2.90	5.58	----------	----------
1923	----------	4.10	3.03	5.16	----------	----------
1924	----------	5.50	3.30	6.12	----------	----------
1925	----------	6.50	3.45	6.61	----------	----------
1926	----------	6.20	3.50	6.00	----------	----------
1927	----------	4.10	3.00	5.62	----------	----------
1928	----------	3.80	3.30	4.63	----------	----------
1929	----------	3.80	3.10	4.24	----------	----------
1930	----------	4.00	----------	3.98	----------	----------

Compiled as follows: Prices in Hamburg and France to 1891, Wholesale Prices, Wages and Transportation, Senate Committee on Finance, Mar. 3, 1893, 52d Cong., 2d sess., Senate Report 1394; Hamburg, 1892–1896, Statisticher Auszug und Verschiendene Nachweise in Bezug auf Hamburg Handelszustande in Jahre, 1896; London prices, 1850–1906, Augustus Sauerbeck, Journal Royal Statistical Society, 1907–1928, Editor of the Statist, Journal of Royal Statistical Society; Tokyo prices, 1868–1927, Statistics of Rice Department of Agriculture and Commerce, Japan, 1928, Weekly Circular, London Rice Brokers' Association; India, index numbers of rice, C. M. Vakil and S. K. Muranjan, Currency and Prices in India; New York, 1851–1899, Wholesale Prices, Wages and Transportation, Pt. I, 1898; 1890–1926, U. S. Bur. of Labor Statis. Bull. 440; and yearly bulletins.

[2] No report.

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FEEDING PUNCTURES OF MIRIDS AND OTHER PLANT-SUCKING INSECTS AND THEIR EFFECT ON COTTON

By W. V. KING, *Senior Entomologist, Division of Insects Affecting Man and Animals,* and W. S. COOK, *Assistant Microscopist, Division of Cotton Insects, Bureau of Entomology*[1]

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INTRODUCTION

Observations made in Texas in 1924, after the discovery of an infestation of cotton with the cotton flea hopper (*Psallus seriatus* Reut.), aroused the suspicion that this insect was the carrier of a disease producing a serious disorder of the cotton plant.[2] In severely injured plants the very small squares may be almost completely destroyed, and marked changes in growth characteristics may occur. The studies on which this bulletin is based were begun at Tallulah, La., in 1927, for the purpose of obtaining more exact information as to the character of the damage produced by the cotton flea hopper and other plant-sucking insects.

EARLY OBSERVATIONS AND EXPERIMENTS

Previous field and laboratory work had shown that, in addition to the more general symptoms of injury, small swellings were frequently produced on the stems and leaf petioles of the cotton plants infested with Psallus. These characteristic lesions offered a ready means of identifying cotton flea hopper damage, and a series of experiments had been made to determine whether similar lesions could be caused by artificial inoculations with material from crushed insects or injured plant tissues. Painter,[3] using fine needle points,

[1] The authors are indebted to R. L. McGarr and E. R. Tinkham for assistance in the field work during 1928 and 1929.

[2] HUNTER, W. D. THE SO-CALLED COTTON FLEA. Jour. Econ. Ent. 17: 604. 1924.
——— THE COTTON HOPPER OR SO-CALLED "COTTON FLEA." U. S. Dept. Agr. Circ. 361, 15 p., illus. 1926.

[3] PAINTER, R. H. A STUDY OF THE COTTON FLEA HOPPER, PSALLUS SERIATUS REUT., WITH ESPECIAL REFERENCE TO ITS EFFECT ON COTTON PLANT TISSUES. Jour. Agr. Research 40: 485–516, illus. 1930.

reported successful inoculations from crushed insects, but the writers' experiments with similar methods were not conclusive, the punctures with sterile needles often showing as much damage as those made with the crushed insects. Even needle points ground as finely as possible are still very much larger than the piercing parts of the insect's proboscis and almost always cause a reaction in the plant due to the mechanical injury. Pending the development of a more suitable inoculation technic, feeding tests with live insects were begun in 1927, and the present bulletin is restricted to the results obtained by this method of experimentation.

LESIONS CAUSED BY THE FEEDING OF INDIVIDUAL INSECTS IN TESTS

If the lesions in the cotton plant were due to a pathogenic organism transmitted by insects, it was thought highly improbable that all individuals of the species involved would prove to be infective. The first of the present experiments were therefore designed to determine what proportion of the flea hoppers might cause the swellings. In the first tests each specimen was incaged in a small vial attached to a cotton stem or leaf petiole and watched until it began and finished feeding. When the proboscis was withdrawn the place was marked and examined daily for development of a lesion. If the same specimen could be induced to feed several times, each place was tagged separately. As this method of handling and watching the separate insects proved to be tedious and time-consuming, the vials were later fastened to the plants by means of a narrow strip of adhesive tape (Pl. 1, A) and left attached to one point for a minimum period of about 24 hours. Since in warm weather the majority of these insects must feed one or more times in order to survive as long as 24 hours, this procedure was finally adopted for most of the routine work. Part of the experiments were carried out where general insect infestation was light on unprotected cotton, but, in order to eliminate possible complications of the results from feedings by insects other than those in the tests, the major part of the work during this and the following seasons was done with protected plants grown in large screen cages.

In the first series of 24-hour feedings, and also in those which were watched continuously, only a part of the feeding points showed typical swellings within two or three days while others remained entirely negative externally. This evidence, therefore, tended to support the idea of an infective agent. Some of this plant material, however, was prepared for microtomic sectioning, and a careful study of the stained serial sections at the end of the season showed that nearly all the punctures which were negative externally had produced a condition of the internal tissues less extensive but otherwise similar to that found in the definite swellings. In the discussion of the experiments those feeding points will be described as negative where no injury, either external or internal, developed.

The results obtained may be indicated by the following records selected from this series: One nymph applied to seven different places on a cotton plant for about 24 hours each (developing to an adult in the meantime and dying at the last place) caused no external

swellings. Six of these places, upon being sectioned, were found to have internal lesions, and one was doubtful. Another nymph applied the same number of times caused one doubtful injury and six external swellings, all of which were positive upon being sectioned. No external swellings were observed in the case of one female which was observed to feed at three different places and which was afterwards left in a vial attached to the plant for 24 hours. Upon sectioning, internal lesions were found in the tissues in all three places where the specimen had been observed to feed and a questionable lesion in the place where it was confined for 24 hours. This specimen was left attached for a fifth feeding but died before the end of the 24-hour period. A male with the same history caused five external swellings, having fed before dying at the last place. From the tests in the series for 1927, which were ultimately checked up by microscopical examination of sectioned plant material, there was only one individual that produced no identifiable reaction. This one (a nymph) had been observed to puncture the plant in three places.

METHODS EMPLOYED FOR IDENTIFICATION AND STUDY OF LESIONS

The results of this series showed, for one thing, that external swellings could not be relied upon for identifying the damage. During 1928 it was found after a number of trials that comparatively thick free-hand sections stained with safranin provided a rapid and fairly satisfactory method of determining the presence or absence of internal lesions, and this method was employed in much of the routine examination thereafter. When a more careful study was desired, the material was imbedded in paraffin by the usual cytological methods and sectioned with a rotary microtome.

Though various standard killing and fixing reagents were tried, formalin-acetic acid-alcohol was employed as the fixative for most of the material, largely because of its convenience, since it could be used as a preservative as well as a fixative. Free-hand sections from 100 to 200 microns in thickness were cut with the aid of a hand microtome, transferred to the formalin-acetic acid-alcohol fixative, and stained in safranin. The paraffin-imbedded material was cut 10 to 12 microns thick, the sections mounted serially, and though various stains were tested, the material was stained for the most part with Flemming's triple stain, iron haematoxylin, or safranin and light green.

SPECIES INCLUDED IN THE EXPERIMENTS OF 1928

Four other species of Miridae in addition to *Psallus seriatus* were included for comparative observations in the experiments of 1928. Two of these, *Lygus pratensis* (L.) and *Adelphocoris rapidus* (Say), have been definitely connected with field damage to cotton, whereas the other two, *L. apicalis* Fieb. and *Poeciloscytus basalis* Reut., are very seldom found on this host plant.[4] Individuals of each of these species were tested on cotton stems and leaf petioles by the methods previously described and were found to cause lesions which were

[4] EWING, K. P. EFFECTS ON THE COTTON PLANT OF THE FEEDING OF CERTAIN HEMIPTERA OF THE FAMILY MIRIDAE. Jour. Econ. Ent. 22: 761–765, illus. 1929.

indistinguishable from those of *Psallus seriatus*, although the average severity of the damage varied somewhat among the different species.

CHARACTER OF MIRID LESIONS

Small series of experiments in 1927, as well as many others in 1928 and 1929, proved that individuals of the same species vary greatly as to the effect of their feeding punctures, though consecutive feeding punctures of the same individual produced lesions of fairly uniform size. In stained sections the typical mild lesion is usually found to be confined to the cortex or to the cortex and collenchyma (pl. 1, B), and the affected cells are circularly arranged about the center. The terms "lesion" and "hopper damage" have been applied to all such affected areas although in the smaller forms there may be no evidence of any destruction of tissue. The cells are increased in number, often enlarged, and usually stain more densely than those in the normal surrounding tissue. The nuclei are large and prominent, and the general appearance is one of cell activity with more or less distortion due to pressure. From the smallest lesion, in which only a half dozen or so cells are affected, all stages may be encountered up to the most severe forms in which a half or more of the stem or petiole has been affected and a good part of the tissue has been destroyed. (Pl. 2, A and B.)

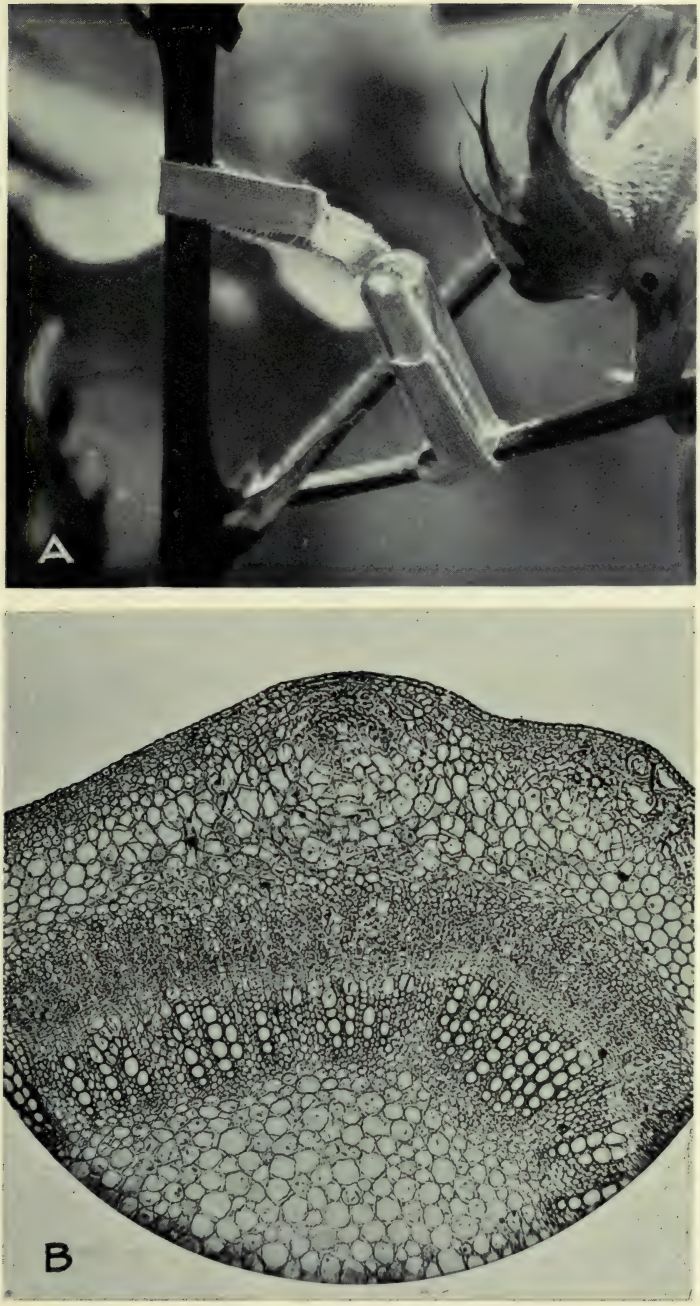
As the area involved becomes larger, collenchyma and epidermis are forced outward to form the swellings which appear externally.[5] When the pressure becomes too great the swellings split open lengthwise of the stem (pl. 2, B), and the exposed tissues on dying form grayish or brownish scars. When the punctures are comparatively deep, extending close to the vascular tissues or into the pith, the swellings may merely compress the tissues internally, and fairly large areas have been noted which did not show at all externally.

In medium-sized lesions the pressure from the increase and enlargement of the cells causes much cell distortion, progressing to the point where the central ones are apparently ruptured. In larger lesions a considerable central area of broken-down cells may be thus involved. (Pl. 2, A.) The remains of cell walls and contents form a conglomerate mass staining brown or red with the stains employed.

That cell multiplication occurs and is involved in the formation of the swellings is shown by the finding of nuclei in various stages of mitosis in the younger lesions. The smaller lesions and those in early stages of development are recognized in the stained sections principally by the large, prominent nuclei in a small group of cells, some of the cells themselves also being enlarged and irregular in outline. (Pl. 2, B.) Iron haematoxylin stains are especially good in bringing out the nuclei. The cell contents are not well preserved in free-hand sections and in these the identification of the smaller lesions depends on the distortion of the cells and deeper staining of the affected area.

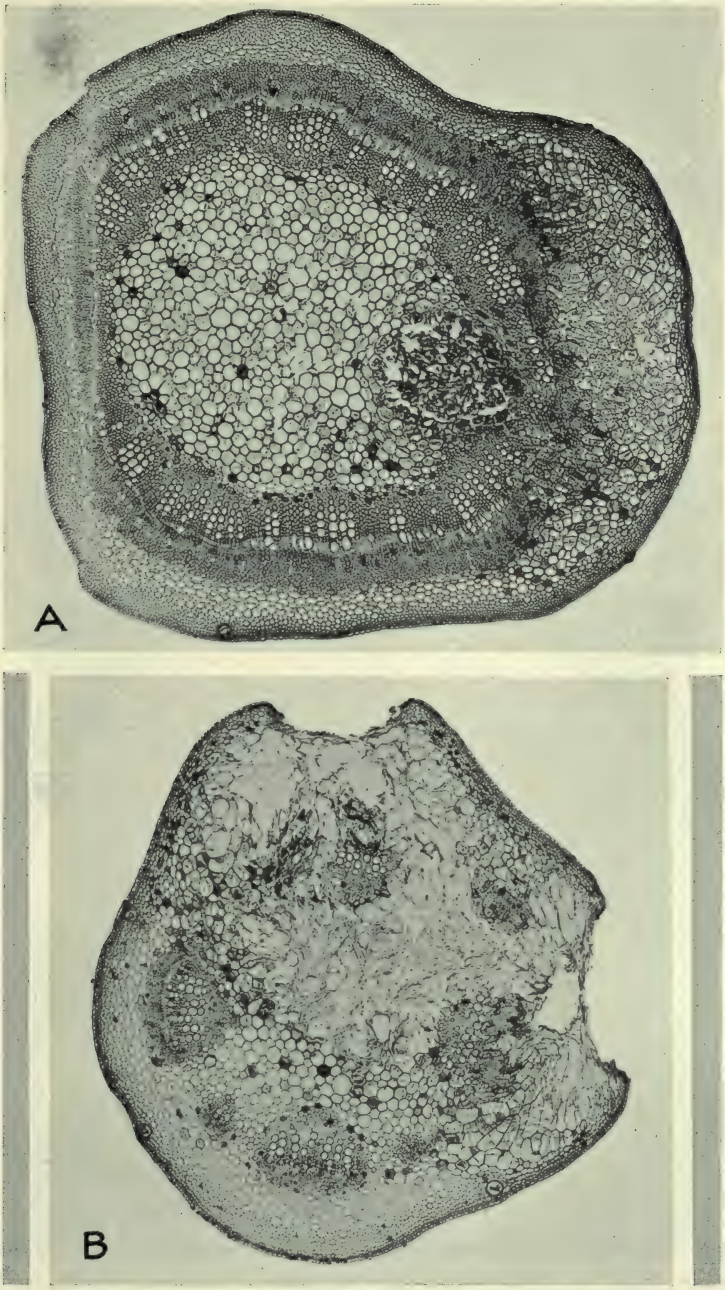
The external swellings usually appear on the second or third day, occasionally on the fourth or fifth. There is one record of a *Lygus pratensis* causing split lesions which appeared in two instances on

[5] In the great majority of cases the swellings from single punctures are not more than 2 or 3 mm. in diameter. An idea of the usual range in size may be gained from the two sections shown in Plates 1, B, and 2, A.



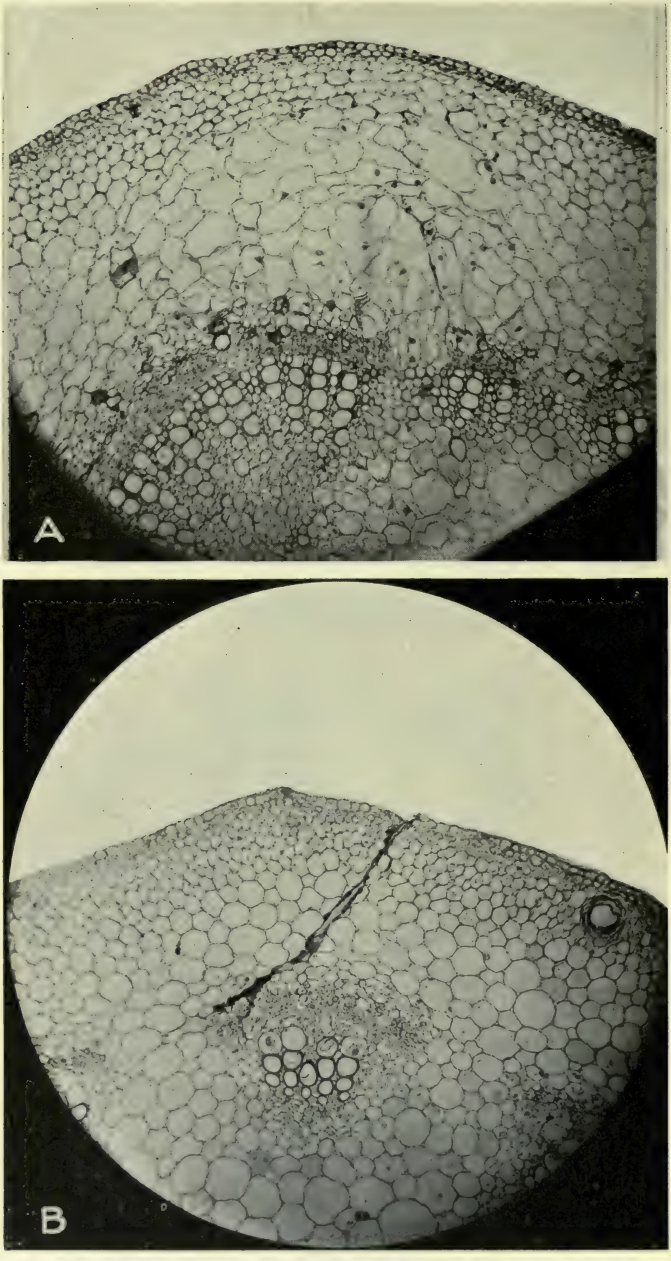
FEEDING PUNCTURES OF INSECTS

A, Glass vial attached to a fruiting branch on a cotton plant. In each vial an insect was confined so it could feed upon a small portion of the stem. A piece of cotton lint or absorbent cotton on each side where the rim does not come in contact with the stem prevented the escape of the insect. B, A comparatively mild lesion confined to the cortex and collenchyma of a cotton stem. This was caused by an observed feeding of an adult of *Psallus seriatus* and produced a slight swelling which was visible externally. The material was preserved for sectioning five days after the feeding. Flemming's triple stain was used. × 50.



SERIOUS INJURIES CAUSED BY THE COTTON FLEA HOPPER

A, A severe lesion extending from the collenchyma to the pith of a cotton stem with some of the vascular tissue affected and with an area of completely broken-down cells in the pith. Caused by an adult kept in the feeding vial 24 hours. The material was preserved for sectioning six days after the attachment of the vial. Flemming's triple stain was used. × 28. B, Two large split lesions in a leaf petiole with over half of the petiole damaged. Caused by a male confined on the plant for 24 hours. Safranin and light green stain used. × 28.



A, A lesion in the cortex of a petiole showing the enlarged cells and nuclei. With a higher magnification one dividing nucleus was seen in this section. The lesion was caused by an adult *Lygus apicalis* confined to the petiole for 24 hours. The material was preserved for sectioning five days afterwards, but the appearance is more typical of the earlier stages of development. Stained with iron haematoxylin. × 92. B, Path of the feeding puncture of an adult *Stictocephala festina* in a leaf petiole. The "sheath" shows a short branch at the tip into the phloem of a vascular bundle. The insect was observed to feed for 30 minutes, and the material was preserved for sectioning six hours later. No cell reaction had as yet developed in the adjacent tissue. Stained with Flemming's triple stain. × 92.

the day following the feeding. These were from watched feedings on protected cotton. The swellings usually reach their maximum size before the fifth day.

A study of the early development of the lesions has been made from plant material killed and fixed for imbedding at various intervals following observed feedings. Preparations from material, made immediately after the punctures were inflicted and 6 and 12 hours thereafter, have not shown definite indications of cell reaction. In several specimens a few enlarged nuclei and in one specimen a dividing nucleus were noted 24 hours after the punctures were made. One preparation, made 24 hours after a puncture from *Lygus apicalis*, showed a comparatively well-developed area in the pith involving about 30 cells (pl. 3, A), whereas nothing definite was found in certain 36-hour and even 48-hour specimens. This series was small and it is probable that some of the latter would not have developed any positive damage.

The lesions may start in almost any part of the tissues. As previously mentioned, the milder forms usually occur in the cortex, but the puncture may go entirely through the vascular tissue and centralize in the pith or, in leaf petioles, in which there is not a complete vascular cylinder, the center may be found between the vascular bundles. Other punctures seem to be very shallow, and the center of the lesion appears in the collenchyma with the affected cells spreading out fanwise into the cortex. In larger swellings the vascular cylinder or a vascular bundle may be involved in the swelling with a portion of it distorted or completely destroyed, and a few instances have been noted in which the center of the lesion seemed to be in the vascular tissue itself.

Injury from the pressure of the rim of the vial has been observed in some instances. This appears as slight depressions or as blistered spots but on sectioning does not extend much below the epidermis.

SPECIES INCLUDED IN THE EXPERIMENTS OF 1929

During 1929 in an effort to find a plant-sucking species which would not cause such lesions in cotton, two more species of Hemiptera and three species of Homoptera that are commonly collected in sweepings from weeds or cotton were added to the experiments. One of the five, a lygaeid, *Geocoris punctipes* (Say), is said to be predacious on other insects and normally not a plant feeder. Another was *Nysius californicus* Stål, a species of the same family. Two of the species, *Homalodisca triquetra* (Fab.) and *Graphocephala versuta* (Say), are cicadellids, and the fifth species, *Stictocephala festina* (Say), is a membracid.

EXPERIMENTAL RESULTS WITH DIFFERENT SPECIES

A summary of the comparative results obtained with the 10 species is given in Table 1. The feedings were all made in the same way by attaching vials containing single insects to leaf petioles or stems (usually branch stems) near the top of immature plants.[6]

[6] No apparent difference was noted between stems and leaf petioles as regards the damage produced. As a rule, young leaf petioles provided better material for sectioning since they contain less woody tissue than do the stems. The places selected, whether petioles or stems, were usually the younger parts of the plant, but those where active growth had been completed or nearly so.

In a few cases the vials were left attached for 48 hours or longer. Otherwise, if the insect was still alive at the end of 24 hours, it was moved to another point and attached as before. The limits of the area exposed to the insect were marked with India ink, and each place was tagged and numbered. The feeding place was then examined daily until about the fifth day after attachment of the vial, when the stem or leaf was cut off and taken to the laboratory. With only a few exceptions, all those which did not show external swellings were sectioned and stained, and the sections of the entire series from the exposed area were examined microscopically. Insects that died or escaped before the end of 24 hours were omitted from the comparative tabulations.

TABLE 1.—*Summary of the results in 1929 of individual feedings by plant-sucking insects on cotton stems and petioles*

[Adults and nymphs exposed in vials for 24 hours or longer]

Family and species	Stage	Individuals	24-hour feedings	Positive reactions		Positive reactions with external swellings	Split lesions
Miridae:		*Number*	*Number*	*Number*	*Per cent*	*Per cent*	*Per cent*
Psallus seriatus	Adult	71	116	115	99.1	89.6	11.3
	Nymph	38	64	64	100.0	98.4	6.3
	Both	109	180	179	99.4	92.7	9.5
Lygus pratensis	Adult	69	165	163	98.8	90.2	33.7
	Nymph	13	18	18	100.0	88.9	22.2
	Both	82	183	181	98.9	90.1	32.6
Lygus apicalis	Adult	25	60	57	95.0	63.2	7.0
	Nymph	6	7	7	100.0	71.4	0
	Both	31	67	64	95.5	64.1	6.3
Adelphocoris rapidus	Adult	29	60	49	81.7	77.6	18.4
	Nymph	16	31	29	93.5	55.2	6.9
	Both	45	91	78	85.7	69.2	14.1
Poeciloscytus basalis	Adult	40	67	67	100.0	100.0	58.2
Lygaeidae:							
Geocoris punctipes	do	4	16	11	68.8	0	0
Nysius californicus	do	6	21	16	76.2	6.3	0
Cicadellidae:							
Homalodisca triquetra	Nymph	5	5	4	80.0	50.0	25.0
Graphocephala versuta	Adult	7	15	15	100.0	33.3	0
Membracidae:							
Stictocephala festina	do	9	28	28	100.0	71.4	10.7

The column headed "Individuals" shows the number of insects that completed at least one 24-hour exposure. The number of exposures ranged from 1 to 8 and averaged about 2 per insect.[7]

The proportion of positive results among the species of Miridae is very high and shows only slight variations between adults and nymphs of the same species or between different species, except the percentage for adults of *Adelphocoris rapidus*, which was somewhat below the average. Some of the largest split lesions have been caused by this species; and as the adults are large and difficult to

[7] The maximum numbers of feedings by single insects were obtained in 1928 when one adult *Lygus apicalis* was kept attached to the plant at different points for 10 days, and an individual of *Lygus pratensis* was observed to feed 16 times in two days.

handle in vials, it is suspected that most of the negative results were due to the failure of the insects to feed. This is borne out by the fact that of 13 negative results with this species 8 were from insects which gave positive reactions at other points.

The lowest proportions of positive reactions were obtained with the two species of Lygaeidae.

The last two columns in Table 1 give comparisons of the relative toxicity of the different species. The percentages are based upon the number of feedings producing positive reactions, and it may be noted that *Poeciloscytus basalis* takes first place in the proportion of external as well as split swellings[8] produced. When confined on cotton plants in cages this species also causes the blasting of squares. Fortunately it does not occur commonly on field cotton.

Lygus pratensis also produces a high proportion of both external and split swellings, but *Psallus seriatus* produces relatively few split swellings. Among the species of which a fair number of nymphs were tested, the adults produce more damage as measured by split lesions, although the nymphs in all cases produce a slightly higher percentage of positive reactions. The proportion of external swellings is variable, but the nymphs of *P. seriatus* produce a higher percentage than the adults.

Among the Homoptera, *Stictocephala festina* produces a fairly high proportion of observable and split swellings, whereas the figures for *Graphocephala versuta* indicate milder effects In four of the five tests with nymphs of *Homalodisca triquetra* lesions were produced, two of which were visible externally, one being a split lesion.

PROPORTION OF INDIVIDUALS GIVING POSITIVE REACTIONS

The proportion of individuals giving at least one positive reaction, which is not shown in Table 1, is even more significant than the percentage of positive reactions based on separate feedings. A summary of this for the five species of Miridae may be given as follows: Of 46 feedings in 1928 the results of which were negative or doubtful (including both watched feedings and 24-hour feedings), 42 were from 25 individuals which gave positive results at other punctures, 2 individuals fed only once, and 1 gave negative results in each of two tests. In 1929 of 19 feedings (including 13 of Adelphocoris) that were listed as negative or doubtful after examination of the sectioned and stained plant material, 14 were from insects that caused lesions at other points, 3 of the individuals completed only one 24-hour exposure, and only 1 completed two feedings, neither of which was definitely positive in result.

The largest number of negative results in 1928 came from a series of watched feedings with *Lygus pratensis*, which was rather surprising in view of other results with this method as well as with this species. One of these insects gave negative results in 4 feedings and positive results in 12; and another gave negative results in 3 cases, questionable results in 2, and a positive reaction in 1. A possible explanation of this may be found in the fact that in order to induce them to feed immediately, the insects for these tests were starved for

[8] A description of the split swellings is given under the heading Character of Mirid Lesions.

longer or shorter periods before being placed on the plants, and some of them probably became so weak that they were unable to complete the feeding in all cases, even after the proboscis was inserted. Something similar has been observed with weakened mosquitoes.

The records are further summarized in Table 2.

TABLE 2.—*Summary of negative results obtained in 1928 and 1929 from feedings by plant-sucking bugs on cotton stems and petioles*

	1928	1929	Total
	Number	*Number*	*Number*
Feedings recorded as negative or doubtful	46	19	65
Individual insects involved	28	18	46
Individual insects which caused positive reactions at other points	25	14	39
Insects which fed only once	2	3	5
Insects which gave two negative results	1	1	2

Among the small series of Psallus feeding in 1927, one nymph, as mentioned previously (p. 3), produced negative results in two cases and doubtful results in one. This makes a total of only three individuals out of the entire number tested that produced more than one negative and no positive reactions. Five others were tested only once and possibly did not feed. The general conclusion to be drawn is that nearly all individuals of these species may be expected to cause a reaction in the plant similar to that which is recognized as hopper damage. A very few may be actually nontoxic.

In view of these results it was not altogether surprising to find that the homopterous species caused similar lesions and a high percentage of positive reactions from feedings. It may be well, however, to warn against the conclusion that all these species are potential pests of cotton. Several of them, although taken occasionally or frequently on cotton, have not been connected in any way with field damage. The two so-called sharpshooters, *Homalodisca triquetra* and *Oncometopia undata* (Fab.), which are often abundant on cotton, apparently confine their attention to the stems, and as the lesions produced here are usually mild, little or no measurable damage seems to result.

THE PATH OF THE FEEDING PUNCTURES

Of special interest in the case of the three species of Homoptera is the fact that the feeding punctures produce a sharply defined sheath which stains a bright red with safranin. (Pl. 3, B.) This makes it possible to follow the path of the proboscis through the tissues and shows quite definitely that these insects search out the vascular tissues in which to feed. If the path does not go straight toward the cylinder or a bundle it is usually branched toward the tip, because of the probing of the insect in different directions, and one of the branches may be found to end in the phloem or occasionally the xylem. Well-formed sheaths have been found in tissues killed for sectioning immediately after the puncture of *Stictocephala festina.*

In the case of the Miridae, material preserved soon after punctures were observed shows nothing to indicate the path taken by the

proboscis and usually little or no evidence of injury. At the most, two or three collapsed cells that seemed to have been punctured have been found. In older material preserved after the lesions are well developed, occasional specimens show an irregular brownish streak, which may have been the line of the original path, running for a short distance through the center of the lesion. Deadened cell walls take a reddish or brownish stain and may also appear through the lesion as a short streak, but these are as apt to be at right angles to the direction of the proboscis as otherwise and are usually rather easily distinguished from the broad sheath of material around the path of the Homoptera puncture. It should be mentioned, however, that in a few microtome-sectioned specimens of 5-day-old lesions caused by Stictocephala there are certain indications that the sheath material is gradually absorbed or diffused by the plant, as in these sections the paths are broken and not well defined.

Of further interest in connection with these observations is the fact that the sheaths are similar to, and perhaps identical with, those described by Horsfall [9] and others around the feeding punctures of several species of aphids in various plants. This writer discusses the nature of the sheath material and is inclined to the opinion that it is a secretion of the cells as a reaction to the wound stimulus. In view of the fact that well-defined sheaths have been found immediately after the puncture, it seems likely that the red staining substance results from the action of the saliva of these species on the middle lamella (the intercellular layer) which the paths seem mostly to follow.

In addition to the sheaths, cell multiplication occurs in the area about the punctures made by the species of Homoptera, developing to the point of tissue destruction, and the effect is quite similar in general to that in mirid lesions.

DISCUSSION OF RESULTS

From the experiments and a histological study of affected plants no indications have developed that a living virus is involved. The insects tested have been obtained from various host plants, and the fact that practically all individuals of 10 species (some of them widely separated systematically) produce a condition in cotton stems and leaf petioles similar to that recognized as true hopper damage almost certainly shows that it is normally associated with the feeding punctures and is probably due to the saliva injected. The toxicity of different individuals is decidedly variable, and this would seem to be consistent with the idea of a chemical irritant.

Another point is that the lesions are quite definitely limited and show no tendency to extend throughout the plant. It is possible that a virus might enter the vascular system and be carried to other parts. In no instances, however, either in the present work or in that of Painter, have young squares been caused to drop by the feeding of the insects on other parts of the plant, except within a very short distance of the squares themselves. A certain similarity between the initial reaction of the plant cells to the feeding punctures

[9] HORSFALL, J. L. THE EFFECTS OF FEEDING PUNCTURES OF APHIDS ON CERTAIN PLANT TISSUES. Penn. Agr. Expt. Sta. Bul. 182, 22 p., illus. 1923.

and to wound stimuli (as represented by needle punctures) is also indicative of the local character of the lesions.

In connection with the subject of infection, reference should be made to a peculiar, deeply staining, granular material which sometimes occurs in the cells of the plant. This was noted by Painter as resembling the slime mold found in clubroot of cabbage and was suspected by him of being related to cotton flea hopper damage. Cells packed with this substance may be found scattered through the pith, cortex, and other tissues, and at times they are extremely numerous. In some of the preparations more or less of an accumulation of the material occurs in the lesions, but with these exceptions it has been found as abundantly in apparently normal, protected plants as in those on which insects have fed. It is not regularly or usually associated with lesions in early stages of development, and an accumulation comparable to that in the older lesions has been observed in tissues reacting to sterile needle punctures. While the nature or origin of the substance is not known, its connection, if any, with the disorder must be purely secondary or accidental.

SUMMARY

Experiments were begun in 1927 and carried through three years, at Tallulah, La., for the purpose of studying the lesions produced in stems and petioles by the cotton flea hopper and other plant-sucking insects. The object was to determine, if possible, whether the injury to cotton following the feeding of these insects was the result of a transmissible virus or due to mechanical or chemical injury.

External indications of injury seemed to prove that only a part of the many insects tested had affected the plants in the way considered characteristic of hopper injury, but later examination by microtome sections through the feeding points showed that practically all punctures resulted in the same type of internal injury. The swelling and breaking open of the lesions in some cases seemed to be the result of more extensive injury rather than injury of another kind.

The size of the lesions produced by one individual in consecutive feedings was often fairly uniform, but the toxicity of different individuals was decidedly variable.

The early reaction of the internal tissues of the plant is recognizable as an enlargement of nuclei and cells at some point along the feeding puncture. This has been observed in material preserved for sectioning 24 hours after the feeding. Dividing nuclei occasionally found in the preparations show that cell division is stimulated, and in this respect the lesions are comparable to the reaction of the plant to wound stimuli. The milder lesions may show only evidence of cell activity and more or less cell distortion, whereas in more severe forms areas of broken-down tissue develop. The full development of the lesion is rapid; and the external swellings, when produced at all, are usually visible by the second or third day.

Individuals of 10 species (7 Hemiptera and 3 Homoptera) were included in the tests. The average severity of the damage by different species was variable. Of the two more important field pests, the percentage of split lesions was 32.6 for *Lygus pratensis* and 9.5 for *Psallus seriatus*. About 7 per cent of the lesions caused by *P. seri-*

atus and 10 per cent of those caused by *L. pratensis* did not show externally. *Poeciloscytus basalis*, a species which is seldom taken on cotton, caused external swellings at every feeding point and produced the highest percentage of split lesions (58.2) of any of the species tested. Of all the individuals that fed more than once only two failed to produce the injury at some feeding point.

The feeding punctures of the three species of Homoptera used in the tests can be traced through the tissues by a well-defined " sheath " which stains a bright red with safranin. This may be found in sections made immediately after the feeding of the insects and is similar in appearance to the sheaths which have been described in aphid punctures. As in the case of the aphids, the paths usually end in the vascular tissue.

No sheath material was found about the punctures made by mirids, and the path taken by the proboscis of the species on which observations were made could not be definitely traced. At the most, in plant material preserved for sectioning soon after the feedings, a few ruptured cells have been found.

The experiments with the 10 species of plant-sucking insects, some of which do not feed naturally on cotton, have shown that nearly all individuals cause a reaction in the tissues of cotton stems and leaf petioles similar to that produced by the cotton flea hopper, *Psallus seriatus*. This is taken to indicate that hopper damage is due to injected substances normally present in the insects and toxic to the plant, rather than to a transmissible disease.

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WASHINGTON, D. C.

SUSCEPTIBILITY OF BARLEY TO LEAF RUST (PUCCINIA ANOMALA) AND TO POWDERY MILDEW (ERYSIPHE GRAMINIS HORDEI)[1]

By E. B. MAINS, formerly *Associate in Botany, Purdue University Agricultural Experiment Station,* and *Agent, Division of Cereal Crops and Diseases,* and MARY L. MARTINI, *Assistant Botanist, Division of Cereal Crops and Diseases, Bureau of Plant Industry*

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INTRODUCTION

Since very little information was available concerning varietal susceptibility of barley to leaf rust (*Puccinia anomala* Rostr.), a survey of barley varieties has been made as part of the cooperative investigations between the department of botany of the Purdue University Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry. Early in these studies abundant infection with powdery mildew (*Erysiphe graminis hordei* Marchal) developed, and it was noted that there were marked differences in the relative susceptibility of varieties. Studies on both fungi were continued on seedlings in the greenhouse, and leaf rust also was studied in field plantings at La Fayette, Ind.

LEAF-RUST STUDIES

In 1924, through the kindness of H. V. Harlan and M. N. Pope, of the Division of Cereal Crops and Diseases, more than 600 varieties and selections of barley were received for investigation. All these were studied in the seedling stage in the greenhouses of the agricultural experiment station of Purdue University. Each variety and selection was inoculated when in about the second or third leaf. The plants were inoculated the first year by the scalpel method, as has been reported for similar studies of leaf rust of wheat.[2] In the following years the seed of varieties was sown in rows in the greenhouse bed. When the plants had reached the proper size they were inoculated by shaking heavily rusted barley over the seedlings.

[1] Cooperative investigations between the department of botany, Purdue University Agricultural Experiment Station, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

[2] MAINS, E. B., and JACKSON, H. S. PHYSIOLOGIC SPECIALIZATION IN THE LEAF RUST OF WHEAT, PUCCINIA TRITICINA ERIKSS. Phytopathology 16: [89]–120, illus. 1926.

After being given a fine spray of water, they were covered with muslin held up from the plants by 12-inch pot labels placed at intervals in the bed. The muslin was then wetted, and the plants were left covered 12 to 24 hours. A high humidity was obtained in this way, and a very uniform and severe infection developed. This method greatly reduces the labor of inoculation and has been employed by the senior writer in all cases where large numbers of varieties have been studied. Only one culture of the rust was allowed in the greenhouse, thus obviating possible complications from a mixture of physiologic forms.

The reaction of seedlings in the greenhouse was classified according to types of reaction. Highly resistant was denoted by 0, very resistant by 1, moderately resistant by 2, moderately susceptible by 3, and very susceptible by 4. In the field the rust reaction was indicated by the percentage of uredinia on the variety.

In the spring of 1924 the complete set of varieties was sown in short rows in the field at La Fayette, Ind. The rust was started in this nursery by dusting the rows with heavily inoculated plants from the greenhouse. In subsequent years the number of varieties was reduced, only those showing some promise of value because of resistance or outstanding agronomic value being retained.

As has been described elsewhere,[3] [4] it was found during the course of these studies that at least two physiologic forms of the rust occurred in the United States. These are distinguished by the reaction of a number of varieties of barley. In Table 1 are shown the reaction of varieties to physiologic form 1 in the seedling stage in greenhouse studies during the winters of 1924 and 1925, and the field reaction of the maturing plant in 1924. It is evident that there is considerable difference in the reaction of varieties. The majority of them were very susceptible (type 4) in the seedling stage.

TABLE 1.—*Reaction of barley varieties to physiologic form 1 of the leaf rust of barley (Puccinia anomala) in greenhouse and field studies, 1924–25*

Variety [a]	C. I. No. [b]	Probable origin	Ecological group	Reaction to [c] physiologic form 1 in greenhouse		Field [d] reaction, 1924
				1924	1925	
Hordeum vulgare pallidum:						
Abed July	1390			4	4	10–24
Abundio	1412	Persia		2		65
Abyssinia	361	Ethiopia		4	4	25–49
Do	949	do	[3]	4		50–64
Do	950	do		3		25
Do	951	do		4		50–64
Abyssinian	1216	do		4	4	25–49
Do	1217a	do		4		25
Do	1217b	do		4		T–9
Do	1218	do		4		25–49
Do	1219	do		4		25–49

[a] Varieties classified according to the following publication: HARLAN, H. V., THE IDENTIFICATION OF VARIETIES OF BARLEY. U. S. Dept. Agr. Bul. 622, 32 p., illus. 1918.

[b] C. I. denotes accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

[c] 0=Highly resistant, no uredinia produced, infection evident as necrotic spots without uredinia; 1=very resistant, uredinia few, small infection mostly evident as necrotic spots without uredinia; 2=moderately resistant, uredinia moderately abundant, moderate in size, in necrotic spots, necrotic or chlorotic spots often without uredinia; 3=moderately susceptible, uredinia moderate to large, moderately prevalent, usually accompanied by some chlorosis; 4=very susceptible, uredinia large, abundant, with little or no chlorosis. Percentage of uredinia compared with the number possible. T=trace.

[d] Field reaction given as percentage of uredinia as compared with the amount possible.

[3] MAINS, E. B. STUDIES IN RUST RESISTANCE. Jour. Heredity 17:313–325, illus. 1926.

[4] ——— HOST SPECIALIZATION OF BARLEY LEAF RUST, PUCCINIA ANOMALA. Phytopathology 20:873–882, illus. 1930.

TABLE 1.—*Reaction of barley varieties to physiologic form 1 of the leaf rust of barley (Puccinia anomala) in greenhouse and field studies, 1924–25*—Continued

Variety	C. I. No.	Probable origin	Ecological group	Reaction to physiologic form 1 in greenhouse		Field reaction, 1924
				1924	1925	
Hordeum vulgare pallidum—Continued.						
Abyssinian	1221	Ethiopia		4		25–64
Do	1223	do		4		25–34
Do	1226	do		3		65–74
Do	1227	do		3		50–64
Do	1228	do		3		50–64
Do	1231	do		2	3	25
Do	1233	do		4		100
Do	1237	do		4		35
Do	1241	do		4		50
Do	1243	do		1	0	T
Acanthus	1095	Sweden	Manchuria	4		100
Alcazar	1096	do	do	4		75
Alexis	968		Hybrid	4		65
Amarillo	1073	China		4	4	75
Apalan	1347			0	0	10–24
Arabel	896		Tennessee Winter × Black Arabian	4		100
Argentine	223	North Africa	Coast	4	4–	5–9
Azov	1028			4		15
Baker	975	Asiatic Turkey				
Barbary	695	North Africa	Coast	4	3–	5–14
Bashaw	1018			4		65–74
Blue Ribbon	611	Manchuria	Manchuria	4	3	25–34
Caballero	1006	Russia	do	4		50–64
Cadmus	1054	China		4	4	75
California Mariout	1455	North Africa	California Mariout	4	3	25–49
Callas	2440	Peru	Coast	2	1	T–9
Canada Winter	713	Europe	Tennessee Winter	4	4	65–74
Canadian Lake Shore	2515		Manchuria	4		65
Cape	557	do		2	1	15
Do	1268		Coast	3		25–49
Do	1387		North Africa	4	4–	15
Carytid	1108	Switzerland	Manchuria	4	4	50
Cebada	1055	China		3	4–	75
Champean	990	Siberia	Manchuria	4		100
Cheliff	1074	North Africa	Coast	4	2	T
Chevron	1111	Switzerland		4		100
Chile	663	North Africa	Coast	0	0	T–9
Chilga Arpa	744	China		1	0	25–49
Clancy	1002	Russia	Manchuria	4	4	25
Club Mariout	261	Egypt	Club Mariout	3	2–	T
Coast	276	North Africa	Coast	1	0	T
Do	626	do	do	3	1	5–14
Do	690	do	do	2	1	T
Do	691	do	do	1	0	T
Do	2369	do	do	4		65
Consul	1061	China		2+	4	25–49
Cortile	1123		Smooth × Indian Head.	4		25–49
Crocket	1094	Sweden	Manchuria	3		75
Cusado	895		Tennessee Winter × Black Arabian.	2	4	75
Czar	1005	Russia	Manchuria	4	4	50
Daniels	971	Manchuria	do	1	0	50–64
Dinar	729	North Africa		3		25–49
Duplex	2433	Russia		2	5	25–49
Eagle	913	Manchuria	Manchuria	4		50–64
Do	1320		do	4		65
Do	1324	Manchuria	do	4		50
Featherston	911	do	do	4		50–64
Do	954	do	do	3	4	25
Do	1118	do	do	2+	4	T–14
Do	1119	do	do	4		65
Do	1120	do	do	0	0	50–64
Fengsein	1040	China		4	4–	50–64
Finland	581	Finland	Arctic Manchuria	4		25–49
Fleche	1263	South Russia		4	4	75
Galwan	2348	Central Asia		4		65–74
Gehangir	1089	India		1	2	T
Gobi	1058	China		4	4	75–100
Greece	221	Greece	Coast	4	4	T–9

TABLE 1.—*Reaction of barley varieties to physiologic form 1 of the leaf rust of barley (Puccinia anomala) in greenhouse and field studies, 1924–25*—Continued

Variety	C. I. No.	Probable origin	Ecological group	Reaction to physiologic form 1 in greenhouse		Field reaction, 1924
				1924	1925	
Hordeum vulgare pallidum—Continued.						
Gurov	1099	Russia		4		65
Han River	206a	China		4		75-100
Do	206b	do		4		75-100
Harem	1019	North Africa		4		50
Haua	734	India		4		15
Hidalgo	1020			1	0	T
Hisein	1053	China		2		50-64
Hodge	982	Turkestan		3		50-64
Judith	1038	China		4	4	100
July	1082	Denmark		4		50
Kaosein	1042	China		4	4	25-49
Khanaka	743	Chinese Turkestan		4		75
Khartum	2367	North Africa		2		25-49
Kopeck	869	do	Coast	3	2	T-9
Korsbyg	918	do		2	3	25-34
Kumflide	730	China		3		25-49
Kunshan	1065	do		4	3	25
Kusan	1315	Egypt		4		100
Kwan	1016	India		3	2	T-24
Ladrone	696	Palestine		1	3—	T-14
Lake City	1126	Manchuria	Manchuria	4		75
Large-Grained Winter.	408	Europe	Tennessee Winter	4	2	T-14
Leh	700	India		2	2	35-49
Liland	1323		Manchuria	4		65
Losein	1070	China		4	4	50
Lubin	2435	Russia		4		50
Luth	908	Manchuria	Manchuria	4		65
Do	972	do	do	2	2	5-14
Malster	1025			4		50-64
Mammoth Winter	220	Europe	Tennessee Winter	3		
Manchuria	244	Manchuria	Manchuria	2		25-34
Do	354	do	do	4		50
Do	576	do	do	4	4	15-24
Do	643	do	do	4		50-64
Do	956	do	do	4		50-64
Do	1251	do	do	4		75
Do	1397	do	do	4		50
Manchuria Pedigree.	1244	do	do	4		50
Manmoy	2456	North Africa	Coast	4	4—	T-5
Mecca	1051	China		3	2—	25
Mecknos Moroc	1379		Coast	1	0	T
Michung	1160	China		4		25-49
Mignon	999	Russia	Manchuria	4		100
Monte Cristo	1017	India		2-3	2+	5-9
Nani Tal	1087	do		4	4	T
Nanook	1329	Manchuria	Manchuria	4		65
Niver	737	China		3	4—	65
Notherson	1093	Sweden	Manchuria	3		75
Oderbrucker	940	Manchuria	do	1	0	50-64
Do	957	do	do	1	0	50-64
Do	969	do	do	4		50
Do	1137	do	do	4	4	75-100
Do	1396	do	do	4		50
Odessa	182	Russia	Odessa	4		50
Do	916	do	do	2	2	25-49
Do	927	do	do	4		65-74
Do	934	do	do	2		50
Do	974	do	do	4		25-34
Olonets	198	Russia	Arctic	4		50
Pannier	1330			0		75
Peru	653	North Africa	Coast	3	2	5-24
Peruvian	935	do	do	1	1	T
Petchora	2425			4		65
Pidor	901		Tennessee Winter	3	4	75
Poda	652	North Africa	Coast	4	2	5-14
Pontius	731	China		2	3	50
Quinn	1024	North Africa	Coast	2	0	T
Rasput	996	Russia	Manchuria	4		100
Red River	973	Manchuria	do	4		50-64
Rival	2345			3	2	T
Royal	1252		Swedish×Baxter	3		75

TABLE 1.—*Reaction of barley varieties to physiologic form 1 of the leaf rust of barley (Puccinia anomala) in greenhouse and field studies, 1924–25*—Continued

Variety	C. I. No.	Probable origin	Ecological group	Reaction to physiologic form 1 in greenhouse		Field reaction, 1924
				1924	1925	
Hordeum vulgare pallidum—Continued.						
Rubard	2434	Russia		3		50
Ruble	870			4	3	5–14
Sagina	1269	North Africa	Coast	4		25
Salamanca	689	Spain		3		25–34
Sandrel	937	North Africa	Coast	4		50–64
Scottish Pearl	277	Europe	Tennessee Winter	4	4	25–49
Servian	915	Serbia		4		50
Shale	2430	Russia		4		50
Shorthead	2364	North Africa		3	2	T
Silver King	2374	Manchuria	Manchuria	4		50–64
Squarehead Winter.	252	Europe	Tennessee Winter	4		0–T
Sultan	997	Russia	Manchuria	3		100
Sulu	1022			3	0	T
Summit	929		Swedish×Baxter	3	3–	15–34
Do	1136			4		50
Sumson	1092			4		50–64
Surprise	171		Swedish×Baxter	3–4		65–100
Telli	194	North Africa	Coast	3	2	0–T
Tenkow	646		Tennessee Winter × Hankow.	1–4		35–49
Tennessee Winter	257	Europe	Tennessee Winter	4	4	65
Do	876	do	do	4		65–74
Texas Winter	554	do	do	4		65–74
Tonot	1012	North Africa	Coast	2	3	T–14
Trebi	936	Asiatic Turkey	Trebi	4		25
Turkestan	711	Turkestan		1	1	T–14
Tystofte	1322	Denmark		4		10–24
Unnamed	497	Egypt		3		25
Do	1383			2	2	T
Do	2346			4	4–	T
Do	2350			4	4–	T
Do	2368	Siberia	Manchuria	4		65
Do	2371			4		65
Do	2372			4		35–49
Do	2373			4		50–64
Do	2380	Ethiopia		4		65–74
Do	2384	do		4		10–14
Do	2410	do		2	3	25–49
Do	2411	do				25
Do	2412	do		3		65
Do	2418	do		4		25–49
Do	2420			2		15–24
Do	2421			4		50
Venus	736	China		3	4	75
Victor	1411	Asia Minor (Persia)		4		75
Wansnipe	1050	China		3		50–64
Weider	1021			1	0	T
White Gatami	920	Manchuria		4	4–	65–74
White Russian	706	Russia		4	4	15–24
Winter	667	Turkestan		4	4	50–64
Wisconsin Winter	519	Europe	Wisconsin Winter	4	4	15–24
Woodrow	986	Russia	Manchuria	4		50
Wusein	1044	China		4		65–74
Youshan	1068	do		2		75–100
Yuwan	1071	do		4		50
Zond	1138	Asiatic Turkey	Trebi	4		50
Hordeum vulgare pallidum parallelum:						
Abyssinia	943	Ethiopia		3		50–64
Do	946	do		4		15–24
Abyssinian	2193		Abyssinia	4		65
Gambrinus	1066	China		2		25–60
Hordeum vulgare pallidum pyramidatum:						
Abacus	1088	India		0	0	T
Abyssinia	2192	Ethiopia		1	1–	T
Abyssinian	2194	do		4		65
Do	2195	do		4		65
Chile Brewing	657			1	1	5–24
Club Mariout	932	North Africa	Club Mariout	3	2	25
Do	2334	do	do	3	3	T
Console	1112	Switzerland		2	3	T–4

TABLE 1.—*Reaction of barley varieties to physiologic form 1 of the leaf rust of barley (Puccinia anomala) in greenhouse and field studies, 1924–25*—Continued

Variety	C. I. No.	Probable origin	Ecological group	Reaction to physiologic form 1 in greenhouse		Field reaction, 1924
				1924	1925	
Hordeum vulgare pallidum pyramidatum—Continued.						
Czech	1023			2	2	T–14
Filer	1059	China		4	4	75–100
Kobeck	2436	Russia		4		50
Lochink	2460	China		2	3	5–24
Malwet	2459	do		3	4–	50–64
Moy Wah	1064	do		4		100
Mulyan	2453	do		3	3	25–49
Pasha	984	Russia		4	4	75
Pegan	2454	China		4	4	25–49
Rakoff	2432	Russia		4		25–49
Russia	1371			4		50–64
Scarab	995	Russia		2		100
Welcome	2439	do		4		65
Winter Club	592	Europe	Winter Club	4		75
Hordeum vulgare pallidum rikotense:						
Andrew	1351		Leiorrhynchum×Mariout.	4		35
Blarney	1303		Lion×Manchuria	4		25
Catts	1283		Bay Brewing×Lion	4		65
Cheddar	1307		do	4	4–	5–9
Coates	1349		Leiorrhynchum×Mariout.	4		65
Feline	1284		Lion×Featherston	4		65
Fergel	1360		Mariout×Leiorrhynchum.	4		65
Gilette	1359		do	4		25
Hero	1286		Club Mariout×Lion	3	3	10–24
Heron	1299		Manchuria×Lion	4		65
Hopper	1285		Bay Brewing×Lion	4		65
Hurst	1304		Featherston×Lion	4		65
Jusborne	1355		Lion×Manchuria	4		75
Lariout	1350		Leiorrhynchum×Mariout.	3		25
Leader	1282		Bay Brewing×Lion	4		25–49
Limerick	1302		Manchuria×Lion	2		50
Louden	1308		Bay Brewing×Lion	4		25–49
Lyman	1358		Lion×Manchuria	4		50
Minorca	1357		do	4		35
Morrison	1361		do	4		25–49
Newcomb	1368		Mariout×Leiorrhynchum.	3	4	25
Nigger	1301		Manchuria×Lion	2		75
Norbec	1363		Bay Brewing×Lion	3		50
Olman	1554		Featherston×Leiorrhynchum.	4		65
Osborn	1364		do	4		50
Phoebe	1305		Bay Brewing×Lion	4	4–	5–9
Plymoth	1356		do	4		50
Preston	1348		Leiorrhynchum×Mariout.	4		15
Ramsey	1366		Mariout×Leiorrhynchum.	4	4	5–24
Theodore	1300		Manchuria×Lion	4	4	25
Unnamed	1352		Leiorrhynchum×Mariout.	3		65
Do	1353		Bay Brewing×Lion	2		65
Do	2331		Smooth Awn×Manchuria.	4		65
Vaughn	1367		Mariout×Leiorrhynchum.	4	3	25
Vitz	1306		Bay Brewing×Lion	4		65
Hordeum vulgare pallidum coerulescens:						
Abyssinian	1235	Ethiopia		4		50–64
Do	1242	do		4		75
Albacete	1128	Spain		4		65
Algerian	1179	North Africa	Coast	4	4–	15–24
Arequipa	1256	do	do	0	0	0
Do	2329	do	do	2	1	0
Barquis	1076	do	do		2	T
Blubak	2445	China		4		25–49

TABLE 1.—*Reaction of barley varieties to physiologic form 1 of the leaf rust of barley (Puccinia anomala) in greenhouse and field studies, 1924–25*—Continued

Variety	C. I. No.	Probable origin	Ecological group	Reaction to physiologic form 1 in greenhouse		Field reaction, 1924
				1924	1925	
Hordeum vulgare pallidum coerulescens—Continued.						
Bolivia	1257	North Africa	Coast	1	0	0
Do	1365	do	do	3	4–	T
Brutus	1011	North Africa	do	3	2+	25
Buchiang	1043	China		4	4	65–74
Cabeza	1437	North Africa	Coast	1	1	T–14
Canadian Malting No. 2	1034	North Europe		4		75
Cape	1026	do	Coast	4	4	75
Do	1386			4	4–	25
Do	1451	North Africa	Coast	2	3	T
Cartouch	1107	Switzerland	Manchuria	3	4	50
Chilean C	1432	North Africa		0	0	T–14
Chilean D	1433			1	0	T
Coast	1430	North Africa	Coast	4		T–14
Do	2332	do	do	4	3	25
Do	2333	do	do	3	3	25
Do	2335	do	do	2	3	25
Colorado	1075	do	do	2	4	25
Coventry	1037	India		3		50
Cromlech	1215	North Africa	Coast	4	2	T
Crypt	1090	India		4	4	T
Cyma	1258	do		4		100
Juliaca	1114	North Africa	Coast	0	0	T–4
Kimberly	1382		do	2		T–14
Koran	1063	China		4	4	50–64
Lynch	919	North Africa	Coast	1	0	15–24
Malting	1129		Manchuria	1	0	50
Manchuria	1178	Manchuria	do	3		65
Do	1435	do	do	2	3	25–34
Do	2330	do	do	0	0	25–49
Maxima	1436			1	1	T–9
Moldavia	392	Rumania	Coast	3		T–4
Norton	1362	Hybrid		4		50
Oderbrucker	1174	Manchuria	Manchuria	3		50–64
Odessa	1438	Russia	Odessa	2	3	25
Persia	1372			4	4	25
Peru	707	North Africa	Coast	3		50–64
Peruvian	1131	do	do	2	1	T
Petro	994	Russia		3		50–64
Roseworthy	2362	North Africa		2		50
Roseworthy Oregon.	1439			2	4–	65
Sabbaton	1266	China		4	4–	75
Sanook	1395			4		5–14
Shorthead	1441	North Africa		4		50
Squarehead	1417	do	Coast	2	4	25
Squarehead Winter.	1267			3	2	25
Tripoli	1115	North Africa		2	2	75–100
Turbat	1254	Asia		4		50
Wanfat	2461	China		4	4	50–64
Hordeum vulgare pallidum subviolaceum:						
Abyssinian	1238	Ethiopia		3		65
Chusein	1039	China		3	4–	100
Coolie	1060	do		4		75–99
Envoy	1045	do		4	4–	100
Fesan	2463	do		4		25–49
Hiangshan	1047	do		3	4	75
Leopold	1057	do		4		75
Misein	1062	do		3		50
Soochow	867	do		3	3	25–49
Squiers	1072	do		4		50–64
Yatlong	2464	do		4		25–49
Hordeum vulgare pallidum eurylepis:						
Wansnipe	2356	China		4	4	75
Hordeum vulgare nigrum:						
Abyssinian	1220	Ethiopia		4		T–14
Do	1222	do		3		T–14
Do	1230	do		2	2+	25
Do	1232	do		4	4	25

TABLE 1.—*Reaction of barley varieties to physiologic form 1 of the leaf rust of barley (Puccinia anomala) in greenhouse and field studies, 1924–25*—Continued

Variety	C. I. No.	Probable origin	Ecological group	Reaction to physiologic form 1 in greenhouse		Field reaction, 1924
				1924	1925	
Hordeum vulgare nigrum—Continued.						
Barbican	1265			4		25
Do	2336			3	3	25
Black Russian	705	Caucasus		3	3	T–14
Donjon	1264			3	4–	25
Gatami	575	Manchuria		2	3	25–49
Do	1413	do		4	4–	25
Ghest	979	Russia		3	2	T
Oswong	697	India		2	3	5–14
Unnamed	2349			2	3	T
Wofut	1009	Russia		4	4	T–24
Hordeum vulgare nigrum leiorrhynchum:						
Black Algerian	708	North Africa		4		100
Chorny	875	Russia		4	4–	50–64
Lion	923	do		4	2	50–64
Nekludowi	1000	do		4		100
Hordeum vulgare horsfordianum:						
Diana	1345		Nepal X	0	0	75
Hooded Spring	716		do	0	1	65–74
Horsford	507		Nepal	0	0	15–24
Do	610		Nepal X	0	0	25–34
Do	1375		Nepal	4	4	25–49
Do	2324		Nepal X	4	4	50
Kipper	1291		do	0	0	65
McFadden	1398		Horsford × Hanna	0	0	50
Do	1399		Horsford × Manchuria.	0	0	50
Do	1401		Hybrid	0	0	100
Do	1402		Horsford × Manchuria.	1	0	65
Do	1404		Horsford × Hanna	0	0	65
Do	1406		do	0	0	65
Do	1408		Horsford × Manchuria.	1	0	50
Do	1409		do	0	0	50
Nuerta	741	China		2	4	100
Sirroche	1289		Nepal X	4		25
Wilder	1346		do	4		35
Hordeum vulgare coeleste:						
Ak Arpa	747	China	Turkestan	2		65–74
Barley Wheat	1384			4		50
Black Hull-less	735	China	Turkestan	4		65
Do	1097	Central Asia	Black Hull-less	2	2	25
Chilga Arpa	2351	China	Turkestan	4		65
Comju	2358	Japan		4		50
Dehra	1085	India		4	4	65
Eremo	1014	do		4		75
Galangatch	727	China		4		75
Gorak	1086	India		4		75
Hankow	197	China	Central Asia	4	4	50–64
Hansee Hull-less	703		Horsford × Hankow	4	4	100
Himalaya	254		Himalaya	4	4–	5–9
Hull-less	699	India		4		65
Do	745	China	Turkestan	4	4	100
Huskless	722	Central Asia		4		100
India	698	India		4	4–	75–100
Do	2318	do		4		65
Do	2319	do		3		25
Iris	998	Russia		4	4	100
Ivory	865	China		2	3	25–34
Kama-orc	694	Japan		4		65
Kharsila	733	India		2	4	50
Kok Arpa	746	China	Turkestan	4	4	50–64
Lokiang	2457	do		4		25–49
Maynang	2429	do		4	4	25–49
Memesh	593	do		4		50
McFadden	1405		Nepal X	4		25–49
Nangmay	2426	China		4	4	50–64
Orkoe	2465	do		2	3	65–74
Pingpong	1056	do		2		50
Pingyan	1067	do		4		25

TABLE 1.—*Reaction of barley varieties to physiologic form 1 of the leaf rust of barley (Puccinia anomala) in greenhouse and field studies, 1924–25*—Continued

Variety	C. I. No.	Probable origin	Ecological group	Reaction to physiologic form 1 in greenhouse		Field reaction, 1924
				1924	1925	
Hordeum vulgare coeleste—Contd.						
Poree	2428	Japan		4		50–64
Robin	991	Russia		4		65
Saggia	1316	Ethiopia		4		100
Sangatsuka	78	Japan		2	4–	50–64
Santizo	1049	China		4	4	50–64
Semet	1314	Ethiopia		4		100
Swedish Hull-less	623			4		50–64
Tatien	665	Asia		4		50
Thomas	1041	China		4		25
Unnamed	671	Ethiopia		4	4	25
Watho	2458	do		4	4–	T–14
Yanehadaka	580	Japan		4		50–64
Zunpakei	692	do		2	4–	65–74
Hordeum vulgare coeleste nudipyramidatum:						
Kamamugi	577	Japan		4		65–74
Taihu	868	China		4	4–	50–64
Tanbash	578	Japan		4		65–74
Hordeum vulgare coeleste himalayense:						
Ederle	1015	India		4	4	65
Himalaya	620	Central Asia	Himalaya	4		25–34
Do	1312		Coeleste×Coast	3	4–	25–34
Do	2448	China		4	4	T–25
Hordeum vulgare coeleste violaceum:						
Black Hull-less	596	Central Asia	Black Hull-less	4	3	5–14
Do	618	do	do	3		65
Do	666	do	do	4	4–	25–34
Do	1027			4		75
Do	2320	Central Asia	Black Hull-less	4		10–24
Do	2449	China		4		50
Mochi-Hadaka	2423	Japan		4		50
Do	2424	do		3		35
Purple Hull-less	1415			4	4–	25
Spain	1370			3	4	25–49
Hordeum vulgare trifurcatum:						
Black Hull-less	1032			4	4–	50
Skinless	1414	India	Nepal	3	4–	25
Lihor	866	China	do	2		T– 9
Nepal	247	India	do	4	3	5–14
Do	250	do	do	4	3	5–14
Do	262	do	do	4	3	T–14
Do	475	do	do	4	3	15–34
Do	489	do	do	4	3	T–14
Do	533	do	do	4	3	5–24
Do	595	do	do	4	3	T–24
Do	598	do	do	3	4–	T–14
Do	1290	do	do	2	3	T–14
Do	1292	do	do	4	4	25–34
Do	1385	do	do	4		50
Do	2322	do	do	4		10–24
Purple Nepal	1373	do	do	2	1	T
Subnepal	2321	do	do	4		25–49
Unnamed	2365	do	do	4		25
Hordeum intermedium haxtoni: Famesh.	616	China	Awnless	4		25
Hordeum intermedium haxtoni tonsum:						
Arlington Awnless	702		Tennessee Winter × Black Arabian	4	4	75–100
Bodzu	753	Japan		4	5	25–34
Bozu	749	do		4	4	100
Huwan	1080	China		3–4	4	100
McFadden	1443			4		65
Nakano Wase	754	Japan	Awnless	3	3	25–49
Saitama-Nishiki	752	do		4	3	50
Hordeum intermedium mortoni nigritonsum:						
Chinerme	1079	China		3	3	100
Nigrate	2444	do		2		25–49

TABLE 1.—*Reaction of barley varieties to physiologic form 1 of the leaf rust of barley (Puccinia anomala) in greenhouse and field studies, 1924–25*—Continued

Variety	C. I. No.	Probable origin	Ecological group	Reaction to physiologic form 1 in greenhouse		Field reaction, 1924
				1924	1925	
Hordeum intermedium nudihaxtoni:						
Unnamed	2352			4		65–74
Hordeum intermedium cornutum:						
Cornutum	724	India		2	4	25–49
Do	1317	South Africa		4		100
Do	2366			4		65
Abyssinia Intermediate:						
Abyssinia	676	Ethiopia		4	3	25
Abyssinian Intermediate	2326	do		4		65
Do	2377	do		4		50
Do	2379	do		4		50–64
Do	2381	do		4		50
Do	2382	do		4		75
Do	2407	do		4	4—	25
Do	2409	do		4		50
Do	2415	do		2	3	25
Do	2514	do		4		75
Black Abyssinian	2383	do		4		10–14
Black Abyssinian Intermediate.	2416	do			4—	25
Mandarin	981	do		4	4	25
Hordeum distichon palmella:						
Alpha	959		Manchuria × Champion of Vermont.	4	4	25–34
Archer	2360	England		4		25
Bolton	177		Swedish × Baxter	4		75–100
Do	922		do	3		65–69
Cleroff	985	Russia		4	4	25
Exedra	1262	South Russia		4	4	25–49
Fidel	1445	Persia		4		75
Golden Grain	2363	England	Thorpe	4		65
Goldthorpe	1424	do	do	4		50
Hanchamont	1121		Hanna × Champion of Vermont.	4	4	25
Khayyam	1117		Tennessee Winter × Black Arabian.	4	4	25
Kinver	2361	England	Chevalier	4		25–49
Newbly	2437	Russia		4		50
Norfut	1007	do		4		50
Odessa	961	do				15–24
Omar	898		Tennessee Winter × Black Arabian.	4	4	75
Do	898		do	2		25–49
Orel	351	Russia	Orel	4	4	5–54
Palestine	939	Palestine		2	2	T–9
Pandora	1077	Persia		4		100
Pasvolski	1103	Russia		4		75
Pryor	2359	England		2	1	25–49
Rex	1388			4	4	15
Roshal	1344		Svanhals	4		50
Semir	1255	Asia		3		50
Shale	988	Russia	Hanna	3		75
Shiraz	1078	Persia		4		25
Silesia	978			4		25–49
Svanson	1342		Smyrna × Svanhals	4		65
Syria	1259	Asia Minor		3	3	T–14
Theda	1293		Moravian × deficiens	4		75
White Smyrna	658	Asia Minor	Smyrna	4		65
Hordeum distichon palmella nutans:						
Abed	1389			4	4	25
Abed Binder	1081		Denmark	4		100
Do	2444	Russia		4		65–74
Do	2447	do		4		65–74
Abyssinia	355	Ethiopia		4		25
Abyssinian	1229	do		4		100
Do	1234	do		4		75
Archer	1418	England		2	4—	35
Australian White	925	Germany	Hanna	4		50
Bander	2354	Russia		4	4	25

TABLE 1.—*Reaction of barley varieties to physiologic form 1 of the leaf rust of barley (Puccinia anomala) in greenhouse and field studies, 1924–25*—Continued

Variety	C. I. No.	Probable origin	Ecological group	Reaction to physiologic form 1 in greenhouse		Field reaction, 1924
				1924	1925	
Hordeum distichon palmella nutans—Continued.						
Bema	1100	Russia		4		65
Benito	1444	Persia		4		75
Benny	1288	Russia		4		50–64
Bohemian	32	Germany	Hanna	4		50
Do	204	Bohemia	Bohemia	4		35–69
Do	933	Germany	Hanna	4		65
Do	1148	Austria	Chevalier	4		65
Broach	1101	Russia		4		65
Calotte	1102	do		4		75
Canadian Battledore No. 1	1033	England		4		50–64
Caucasian	714	Caucasia	Caucasia	4	4	25–34
Chalet	1110	Switzerland	Hanna	4		50
Chevalier	156	England	Chevalier	4		65–74
Do	278	do	do	4		50–64
Do	1245	do	do	3	4	100
Do	1419	do	do	2	1	T–14
Do	2317	do	do	4		65
Do	2375	do	do	4		25
Chevalier II	530	do	do	4	4	25–49
Creel	1298		Moravian × deficiens	4		100
Danish Gold	1391	Germany	Hanna	2	3	10–24
Eider	993	Russia	do	2		65
Ernest	2443	Persia		4		25–49
Forsythe	2442	do		4		25–49
Franconian	679	Germany	Hanna	4		65–74
Do	680	do	do	4		65–74
Frankish	953	do	do	4		75
Gisborne	1030	do	do	4		100
Gold	1145	do	do	3	3	25–49
Goldfoil	928	do	do	4	4	65–74
Goldthorpe	2357			4		75
Gond Gerst	1393			1	1	15–24
Hanna	24	Germany	Hanna	4		50–64
Do	30	do	do	4		75
Do	34	do	do	4		75–99
Do	203	Moravia	do	4	4	25–49
Do	906	Germany	do	4	4	75–99
Do	942	do	do	4		65
Do	966	do	do	4		100
Do	1122	do	do	4	4	75
Hannchen	531	Sweden	do	4		65–74
Do	602	do	do	4		65–74
Do	1425	do	do	4		50
Heil Hanna 1	681	Germany	do	4	4	75–100
Heil Hanna 2	678	do	do	4	3	25–49
Heil Hanna 3	682	do	do	1	1	T–4
Horn	926	England	Chevalier	4		100
Italian	914	Germany	Hanna	4		75–99
Kinver	1029	England	Chevalier	4	4	25
Do	1434	do	do	4		25–49
Kinver Chevalier	587	do	do	4		50
Kirgiz	1253	Asia		4		50
Kirgizean	1426			4		50
Kite	992	Russia	Hanna	4		65
Kitzing	189	Germany	do	4		65
Kolter	987	Russia	do	4		65
Kurall	2450	do		4		25–49
Kurof	1098	do	Hanna	4		50
Lonhals	1343		Smyrna × Svanhals	4		65
Mahrische	912	Germany	Hanna	4		50
Moravian	965	do	do	3	4	75–100
Nesbit	2451	Russia		3		25–49
Paulina	963	Germany	Hanna	4		75
Prentice	917	England	Chevalier	4	3	25–34
Pride of Dakota	218			2	4–	25–49
Princess	529	Sweden	Hanna	3	4–	T–4
Do	603	do	do	4	3	T–14
Do	1428	do	do	4		25
Princessegert No. 18.	1394			4		25
Proskowetz	893	Czechoslovakia	Hybrid	4		25–49

TABLE 1.—*Reaction of barley varieties to physiologic form 1 of the leaf rust of barley (Puccinia anomala) in greenhouse and field studies, 1924–25*—Continued

Variety	C. I. No.	Probable origin	Ecological group	Reaction to physiologic form 1 in greenhouse		Field reaction, 1924
				1924	1925	
Hordeum distichon palmella nutans—Continued.						
Pryor	1429	England		2	3	T-14
Sealand Prentice	1392			4	4—	T-4
Selco	2452	Russia		4		25-49
Shale	2431	do		4		65-74
Steigum	907	Germany	Hanna	4		100
Do	931	do	do	4		75
Striegum	47	do	do	4		75-100
Surprise × Primus	1124		Surprise × Primus	3		65
Tivannes	1109	Switzerland		4		65-74
White Moravian	977	Germany	Hanna	4		25
White Smyrna	195	Asia Minor	Smyrna	4		50-64
Wibley	2438	Russia		2	4—	T-24
Zero	1287	do		4		50
Hordeum distichon palmella erectum:						
Anthony	1341		Smyrna × Svanhals	4		50
Archer	1031	England		2	4—	10-24
Canadian Thorpe	740	do	Thorpe	4		75-100
Duckbill	1420	do	do	4		35
Garton 986	645a	do	do	2		50-64
Do	645b	do	do	4		50
Garton Regenerated Malster.	1421		Hybrid	4		35-49
Gisborne	1422	England	Thorpe	4		35
Golden Grain	1423	do	do	4		65
Golden Melon	958	do	do	4		75-100
Goldthorpe	1340	do	do	4		65
Imperial	617		do	4		50-64
Invincible	590	England	Chevalier × Golden × Standard Melon.	4		65-74
Nesbian	647		Tennessee Winter × Black Arabian.	4		50-64
Pickett	1004	Russia		4		75-100
Primus	532	Sweden	Thorpe	4		65-100
Do	1427	do	do	2		65
Svanhals	187	do	do	2		65-74
Tanchang	1164	China		4		75
Thorpe	921	England	Thorpe	4		75-100
Unnamed	2355			4		65-74
Do	2370			4		75
Hordeum distichon palmella zeocriton:						
Fan	1380	Asia	Zeocriton	4	4—	50-64
Do	1381	do	do	4		50
Hordeum distichon palmella hypianthinum: Abyssinian.	1239	Ethiopia		4		65
Hordeum distichon palmella subviolaceum: Abyssinia.	672	do		4	4	25-49
Hordeum distichon nigricans:						
Black Arabian	202		Asia Minor	4	2	15-24
Black Egyptian	1246	Egypt		3	4	100
Black Smyrna	191	Asia Minor		3		65
Caliph	983	do		2		25
Dentil	1260	do		4		65
Hordeum distichon nigricans persicum: Erak.	1003	Russia		4	3—	5-14
Hordeum distichon angustispicatum:						
Childs	1326			4		65
McFadden	1400		Horsford × Hanna	0	0	100
Do	1403		Horsford × Gold	0	0	65
Do	1407		Horsford × Hanna	1	0	65
Hordeum distichon nudum:						
Baku	253	Central Asia	Baku	4	4	25-49
Do	709	do	do	4		50
Crimean Hull-less	320	do	do	4	4	25-49
Evans	621	do	do	4	3	35-49

TABLE 1.—*Reaction of barley varieties to physiologic form 1 of the leaf rust of barley (Puccinia anomala) in greenhouse and field studies, 1924–25*—Continued

Variety	C. I. No.	Probable origin	Ecological group	Reaction to physiologic form 1 in greenhouse		Field reaction, 1924
				1924	1925	
Hordeum distichon nudum—Contd.						
Gopal	1091	India		4		50
Mesa	2327			4		25–49
Milan	424	Central Asia	Baku	4		65–74
Poppenheim	314	do	do	4	4	25–34
Hordeum distichon nudumianthinum: Irisaka.	1083	India		4	4	75
Hordeum distichon nigrinudum: Jet.	967	Ethiopia		4	4	75
Hordeum deficiens deficiens:						
Abyssinia	2376	do		4		65
Abyssinian	1224	do		3		65
Do	1225	do		2		50–64
Do	1236	do		4		65
Do	1240	do		4		50
Burley	1294		Moravian×deficiens	4		50
Claudia	1297		do	4		75–100
Deficiens	2325	Ethiopia		4		25–49
Kitchin	1296		Moravian×deficiens	4		75
Redfield	1295		do	3		75
Hordeum deficiens steudeli:						
Abyssinia	362	Ethiopia		2		25–49
Blackhull	878			4	4–	75–100
Hordeum deficiens nudideficiens: Buland.	1084	India		3		50

In the group *Hordeum vulgare*, 447 varieties were studied. Twenty-nine varieties of *H. vulgare* were outstanding for resistance in both greenhouse and field. These were as follows: In the variety *pallidum*, Abyssinian, C. I. No. 1243, Apalan, C. I. No. 1347, Callas, C. I. No. 2440, Chile, C. I. No. 663, Coast, C. I. Nos. 276 and 691, Gehangir, C. I. No. 1089, Hidalgo, C. I. No. 1020, Mecknos Moroc, C. I. No. 1379, Peruvian, C. I. No. 935, Quinn, C. I. No. 1024, Turkestan, C. I. No. 711, and Weider, C. I. No. 1021; in the subvariety *pyramidatum*, Abacus, C. I. No. 1088, Abyssinia, C. I. No. 2192, and Chile Brewing, C. I. No. 657; in the subvariety *coerulescens*, Arequipa, C. I. Nos. 1256 and 2329, Barquis, C. I. No. 1076, Bolivia, C. I. No. 1257, Cabeza, C. I. No. 1437, Chilean C, C. I. No. 1432, Chilean D, C. I. No. 1433, Juliaca, C. I. No. 1114, Lynch, C. I. No. 919, Maxima, C. I. No. 1436, and Peruvian, C. I. No. 1131. For the variety *horsfordianum*, the strain Horsford, C. I. No. 507, was outstanding for resistance in both greenhouse and field. In the variety *trifurcatum*, Purple Nepal, C. I. No. 1373, was outstanding.

In *Hordeum intermedium*, 14 varieties were studied. None of them showed marked resistance to physiologic form 1 in the seedling stage in the greenhouse. In the field 5 showed 25 to 49 per cent of rust. In the group of Abyssinian intermediates 13 varieties were studied. None of these showed marked resistance in the greenhouse studies. One, Black Abyssinian, C. I. No. 2383, showed less than 25 per cent of leaf rust in the field in 1924. One, C. I. No. 2415, was moderately resistant (2 to 3) in the greenhouse studies. In the field 5 showed 25 to 49 per cent.

In *Hordeum distichon*, 171 strains were studied. Of these, 7 were rather resistant (0 to 1, 2) in the greenhouse studies. Three showed considerable resistance. In the 1924 field test 17 showed less than 25 per cent of rust. Of these, 2 were highly resistant in both the greenhouse and field, i. e., in the subvariety *palmella nutans*, Gond Gerst, C. I. No. 1393, and Heil Hanna 3, C. I. No. 682, and in the variety *palmella*, Odessa, C. I. No. 961, were highly resistant in the field.

In *Hordeum deficiens*, 13 strains were studied. None of these showed marked resistance in either greenhouse or field.

Resistance to physiologic form 1 as manifested in the seedling stage in the greenhouse was more prevalent in *Hordeum vulgare* than in *H. distichon*. No variety was outstanding for resistance in the *H. intermedium*, Abyssinian intermediates, and *H. deficiens* groups. Too few varieties, however, were studied in these latter groups to justify comparison. Resistance as manifested in the field in 1924 was also much more prevalent in *H. vulgare* than in *H. distichon*.

A few varieties proved far more susceptible in the field than in the greenhouse-seedling test. Thus, in 1924, Chilga Arpa, C. I. No. 744, was classed as 1 in the greenhouse, while it had 25 to 49 per cent of rust in the field. Daniels, C. I. No. 971, showed type 1 in the greenhouse and 50 to 64 per cent in the field. Featherston, C. I. No. 1120, was 0 in the greenhouse and 50 to 64 per cent in the field. Oderbrucker, C. I. Nos. 940 and 957, were type 1 in the greenhouse and 50 to 64 per cent in the field. Pannier, C. I. No. 1330, was type 0 in the greenhouse and 75 per cent in the field. This was especially noticeable in *Hordeum vulgare horsfordianum*, where a number of varieties were highly resistant in the greenhouse and more or less susceptible in the field, notably Hooded Spring, C. I. No. 716, which was type 0 in the greenhouse and 65 to 74 per cent in the field, and McFadden, C. I. No. 1401, which was type 0 in the greenhouse and 100 per cent in the field. A similar situation also occurred in *H. distichon angustispicatum*.

In 1926 a second physiologic form of the leaf rust was discovered.[5] From 1926 to 1929 a selected series of varieties was studied for reaction in the seedling stage in the greenhouse. The results are presented in Table 2. The most resistant varieties belonged to *Hordeum vulgare pallidum*. Such varieties as Abyssinia, C. I. No. 2192, Abyssinian, C. I. No. 1243, Arequipa, C. I. Nos. 1256 and 2329, Bolivia, C. I. No. 1257, Callas, C. I. No. 2440, Juliaca, C. I. No. 1114, Mecknos Moroc, C. I. No. 1379, Peruvian, C. I. No. 935, Quinn, C. I. No. 1024, and Weider, C. I. No. 1021 were outstanding for marked resistance to both physiologic forms in all the tests. Such varieties as Abacus, C. I. No. 1088, Chile, C. I. No. 663, Chile Brewing, C. I. No. 657, Chilean C, C. I. No. 1432, Coast, C. I. Nos. 276 and 690, Danish Gold, C. I. No. 1391, Gond Gerst, C. I. No. 1393, Heil Hanna 3, C. I. No. 682, Kwan, C. I. No. 1016, Luth, C. I. No. 972, Lynch, C. I. No. 919, Peru, C. I. No. 653, Peruvian, C. I. No. 1131, and Turkestan, C. I. No. 711 showed considerable resistance to both physiologic forms. In the other botanical varieties of *H. vulgare* only one agronomic variety, Purple Nepal, C. I. No. 1373, in *H. vulgare trifurcatum*, approached these in general resistance.

[5] MAINS, E. B. Op. cit. See footnote 4.

TABLE 2.—*Reaction of barley varieties to physiologic forms 1 and 2 of leaf rust of barley (Puccinia anomala) in greenhouse studies, 1926–1929* [1]

Variety	C. I. No.	Reaction to physiologic form 1				Reaction to physiologic form 2			
		1926	1927	1928	1929	1926	1927	1928	1929
Hordeum vulgare pallidum:									
Abyssinia	949		4				4		
Do	2410	4	3	4		4	4	4	
Do	2411	3	4			3	4		
Abyssinian	1243	1	0	0	0–2	0	0		0–2
Apalan	1347	0	0	1		4	4	4	
Blue Ribbon	611	4	4				4		
California Mariout	1455	3	3				3		
Callas	2440	1	0–1	0+	0–1	1	1	1	0+–1
Cape	557	1	1–3	3+			2	3	
Chile	663	0–1	0–1	3	1–2+		2–3		1
Chilga Arpa	744	0		0+	0–2+	3	4	3+	4
Clancy	1002		4		4		4		4
Club Mariout	261	2–3	2–3		3		3		3
Coast	276	0	0–2		1–2+	0	1–2		2+
Do	626			3				2+	
Do	690	2	1–2	3	2	0	0–3	2	1–2
Consul	1061	4	3–4		4	4–	4		4
Cusado	895		3–4		4		4		4
Daniels	971	0	0	1	0–2+	4	4	4–	3–4
Duplex	2433	4–	3	4	4	3	3	3+	4
Eagle	913	4	4	3+	4		4	4	4
Do	1320	4	4				4		
Do	1324	4	4				4		
Featherston	911	4	4		4		4		4
Do	954	4	4		4		4		
Do	1118	4	4			4	4		
Do	1119	4	4				4		
Do	1120	0	0–1	0–1	0–1	4	4	4	3–4
Gehangir	1089	2	3		3		3		3
Hidalgo	1020	1				0			
Hisein	1053	4	3–4		4	4–	4		4
Khartum	2367	4–	2	4			3	4	
Korsbyg	918	4	3–4			4–	4		
Kwan	1016		0–1	1	0+		2	2	2
Ladrone	696	4–	2–3				4		
Leh	700	0	0–1	1	0+–1	2+	3	3	3–4
Luth	972	2	2	2–2+	2+	0	2–3	2	3
Manchuria	244	4			4				4
Do	354	4–	3–4				4		
Do	643	4							
Do	956	4	4				4		
Do	1251	4	4				4		
Do	1397	4	4				4		
Mecknos Moroc	1379	0	0	0+	0–2	0	0–1	1	0–1
Oderbrucker	940	0–1	0–1	0	0+–1	4	4	3–4	4
Do	957	0	1	0	0–1	4–	4	4	3–4
Do	969	4	4		4		4		4
Do	1137	3–4	4				4		
Do	1396	4	4				4		
Odessa	182	4	4		4		4		4
Do	916	3–	2–3	3	3		2–3	3+	4
Do	927	4	3–4		3		3		4
Do	934	3	4				4		
Do	974	4	4				4		
Pannier	1330	0	0–1	1	0+–3	4	4	4	3–4
Peru	653	1	0–2	2+	3		3	2	3
Do	707	1–3							
Peruvian	935	0–1	0–1	1	0–2	0–1	1–2	1–2	0–1
Poda	652	2–3	4		3		3		4
Pontius	731	4	3		4	3			4–
Quinn	1024	0	0	0–1	0–0+	0	0	0	0+
Red River	973	4–	4				3–4		
Sandrel	937	4	4				4		
Shorthead	2364			2+				3+	
Squarehead	1417	3	2–3	3		3	3	2+	
Sulu	1022			1–				0	
Telli	194	1–							
Tenkow	646	3–4	3				4		
Tonot	1012	2+	3	2+	4	1	3	3	4
Turkestan	711	2	2–3	2+	2–3	2–3	2	2	2
Unnamed	1383	3	2	2+	3		2–3	2	3
Weider	1021	0	0	0	0–2	0	1	0	0–1
White Gatami	920	4	4		3		4		4
Winter	667	4–							
Wisconsin Winter	519	4	4	4	4		4	4	4
Youshan	1068	4	3–4			4	4		

[1] See footnotes *a*, *b*, and *c* to Table 1.

TABLE 2.—*Reaction of barley varieties to physiologic forms 1 and 2 of leaf rust of barley (Puccinia anomala) in greenhouse studies, 1926–1929*—Continued

Variety	C. I. No.	Reaction to physiologic form 1				Reaction to physiologic form 2			
		1926	1927	1928	1929	1926	1927	1928	1929
Hordeum vulgare pallidum pyramidatum:									
Abacus	1088	0		1+		2		2+	
Abyssinia	2192	1–	0–1	1	1–2	0–1	1	1	0–1
Chile Brewing	657	0	0–1	0–2	1–2+	2–3	1–3	1–2+	2+–3
Club Mariout	932	2–3	3–4				3		
Czech	1023	2	1–2	3	3		3	2+	3
Lochink	2460	4	3–4		4				4
Pegan	2454		4						
Scarab	995	4	4				4		
Hordeum vulgare pallidum rikotense: Unnamed	1353		2–3	4	0	4	4–	4	4
Hordeum vulgare pallidum coerulescens:									
Arequipa	1256	0	0	0–1	0+–2	0	0	0	0
Do	2329	1–	0–1	0+	0–1	0	0	0+	0–1
Barquis	1076	2	2	1	2–3	1	2	2	2
Bolivia	1257	0	0	0+	0	0	0	0	0
Cabeza	1437	0	0–1	3+	0–2+		2	2+	3–4
Cape	1431	4–	3	3+	3	2–3	3	3	3
Chilean C	1432	0–1		0–3+	0–3	2+–3		2+	2+–3
Chilean D	1433	0–1	0	3	0–3+		2–3	2+	2–3+
Coast	2335	2	2	4		4	2–3	3+	
Juliaca	1114	0–1	0	0–1	0–2	0	0–1	0	0–0+
Kimberly	1382	3	3		3	2	3	0–T	4
Lynch	919	0–1		0–3+	0–2+	2		2–3	2–3
Malting	1129	0	0–1+	0–0+	0+	3–4	4	3–4	2–3
Manchuria	1178	4	4			4			
Do	1435	4	3–4	3+			4–	4	
Do	2330	0	0	1		4	4–	3+	
Maxima	1436	3	2	3+	2	2+	3	2+	2
Oderbrucker	1174	4	4				4		
Odessa	1438	3	3	4			4	4	
Peruvian	1131	1	0–1	1	1–2	0	1–2	2	1
Roseworthy	2362	3	3–4			4	4		
Roseworthy Oregon	1439	4–	4	4	3	4	4	4	4
Tripoli	1115	2	2	3		3	3	3	
Hordeum vulgare nigrum:									
Gatami	575	4–	4		3		4		4
Do	1413	3	4	4			4	4	
Oswong	697	4–	2	3	4	3–4	2–3	3	3
Hordeum vulgare horsfordianum:									
Diana	1345			0				4	
Hooded Spring	716	0–1	0–1	0–1	0+	3–4	4	3–4	3–4
Horsford	507	0	0–1+	0	0+	4	4	4	3–4
Do	610	0	0–1	0+	0	4	4	4	3–4
Do	877	0	0–1	0+	0+	4	3–4	3–4	3–4
Do	1375	4	4	3			4	4	
Do	2324		4		4		4		4
Kipper	1291	0	0	0		4	4	3+	
McFadden	1398	0	0	1			4	4	
Do	1399	0	0	0		4	4–	3+	
Do	1401	0	0	1		4	4	4	
Do	1402	0–1	0	0+		4	4	4	
Do	1404	0	0			4	4		
Do	1406			1				4	
Do	1408	0	0	0	0–1	4	4–	3+	4
Do	1409	0	0	0+	0–2	4	4–	4	4
Hordeum vulgare coeleste:									
Ak Arpa	747	4	3			3	4		
Black Hull-less	735	4	4		4		4		4
Do	1097	4–	3		4		4–		4
Hansee Hull-less	703	4	4	4			4	4	
Himalaya	254	4	3–4		4		4		3
Hull-less	699	4	4				4		
Do	745	4	4				4		
Ivory	865	4	4			4	4		
Kharsila	733	4	4			4	4		
McFadden	1405			0+				4	
Orkoe	2465	4–				3			
Pingpong	1056	4–				4			
Pingyan	1067		4						
Sangatsuka	78	4–	4				4		
Zunpakei	692	4–	4		4	4	4		4
Hordeum vulgare coeleste himalayense: Himalaya	620	3–4	4		4		4–		4

TABLE 2.—*Reaction of barley varieties to physiologic forms 1 and 2 of leaf rust of barley (Puccinia anomala) in greenhouse studies, 1926–1929*—Continued

Variety	C. I. No.	Reaction to physiologic form				Reaction to physiologic form 2			
		1926	1927	1928	1929	1926	1927	1928	1929
Hordeum vulgare coeleste violaceum:									
Black Hull-less	596	3-4	4		4		4		4
Do	618	3	4				4		
Do	666	4	4		4		4		4
Hordeum vulgare trifurcatum:									
Black Hull-less	1032	4	4		4		3-4		4-
Lihor	866	2-4	2	3+	2-3	2+	3-4		3
Nepal	247	4	4				4		
Do	250	4	4				3		
Do	262	4	4				4		
Do	475	4	3-4		4		3		3
Do	489	3-4	4	4	4		3	3-4	3
Do	533	4	3-4				4		
Do	595	4-	4-		4		3		4
Do	598	4	3		4		4		4
Do	1290	4	4		4		3		4
Do	1292	4	4		4		3-4		4
Do	1385	4	4				2		
Purple Nepal	1373	0-1	0	1	1-2+	2	2	2	0-1
Hordeum intermedium haxtoni tonsum:									
Arlington Awnless	702	4	4	3-4	4	4	4	4	4
Huwan	1080	4	4		4	4	4		4
Nakano Wase	754	3							
Hordeum intermedium mortoni nigritonsum: Nigrate	2444		4		4	3	4		4
Hordeum intermedium cornutum: Nepaul	724	4	4		4		4		4
Abyssinian Intermediate:									
Abyssinian Intermediate	2415	3	3	4		2+	3	4	
Black Abyssinian Intermediate	2416	3	3	4	4		3	4	3
Hordeum distichon palmella:									
Alpha	959			4				4	
Cleroff	985		3-4				4		
Goldthorpe	1424	4	4				4		
Odessa	961	1-2	1	2	2		1	2	2-3
Omar	898				4				3
Palestine	939	3	2	3	3	2+	4	3	4
Pryor	2359	3	3	4		2-3	2	3+	
Syria	1259	3							
Wibley	2438	4-	3-4			4	4		
Hordeum distichon palmella nutans:									
Abed	1389		3-4				4		
Archer	1418	4-	3	4		4	4	4	
Bohemian	32	4	4				4		
Do	204	3	4		4		4		4
Do	933	4	4				4		
Do	1148	4	4				4		
Chevalier	156	4	4		4		4		4
Do	278	4	4		4		4		4
Do	1245	4	4	4	4		4	3+	4
Do	1419	2	2-3	4			3	4	
Do	2317	4	4				4-		
Chevalier II	530	4	4		4		4		4
Danish Gold	1391	2	0-3	2+	1-2+	0	1	2	1-2+
Eider	993	4	4	4	4	2-3	4	4	4
Goldfoil	928	4	4	4	3	4	4	4	4
Gond Gerst	1393	1-2	0-1	2+	0-2	0	1	1+	2
Hanna	24		3-4				4		
Do	30		4	3+	4		4	3+	4
Do	203	4	3-4		4		4		4
Do	906	4	4	4	4	4	4	4	4
Do	942	4	3		4		4		4
Do	966	4	4		4		4		3
Do	1122	4	4				4		
Hanna Pedigree	34		4				4		
Hannchen	531	4	3-4		4		4		4
Do	602	4	3-4				4		
Hannchen (Hanschen)	1425	4	4				4		
Heil Hanna 1	681	4	4-		4		4		4
Heil Hanna 2	678	2-3	2	3	2		3	2+	3
Heil Hanna 3	682	0	0-1	1-2	0-1		1	2	2-3

TABLE 2.—*Reaction of barley varieties to physiologic forms 1 and 2 of leaf rust of barley (Puccinia anomala) in greenhouse studies, 1926–1929*—Continued

Variety	C. I. No.	Reaction to physiologic form 1				Reaction to physiologic form 2			
		1926	1927	1928	1929	1926	1927	1928	1929
Hordeum distichon palmella nutans—Continued.									
Horn	926	4	4		4		4		4
Kinver Chevalier	587	4	4				4–		
Kirgizean	1426		4				4		
Mahrische	912	4–	4				4		
Moravian	965	4	4				4		
Princess	529	4	4				4		
Do	603	4	4		4		4		4
Do	1428	4	4				4		
Proskowetz	893	4	4	4	4		4	4	4
Pryor	1429	3	3–4	4		3	3	3+	
Steigum	907	4	4				4–		
Do	931	4	4				4		
Striegum	47	4	4		4		4		4
Hordeum distichon palmella erectum:									
Archer	1031	4–	4			4	4		
Goldthorpe	1340	4	4						
Primus	1427	4–	4						
Svanhals	187	4	3–4		4				4
Hordeum distichon nigricans: Black Arabian	202	3							
Hordeum distichon angustispicatum:									
McFadden	1400	0	0	0+		4	4–	4	
Do	1403	0	0	0		4	4	3+	
Do	1407	0–1	0	1		4	2	3+	
Hordeum distichon nudum:									
Baku	253		4		4		4		
Evans	621	4	4		4		4		4
Hordeum deficiens deficiens:									
Abyssinian	1225	4	4			4	4		
Hordeum deficiens steudeli:									
Abyssinia	362	4–	4	4	4	4	4	4	
Blackhull	878	4	4		4		4		4

The few varieties of *Hordeum intermedium* were more or less susceptible to both physiologic forms. In *H. distichon*, in the group *palmella*, Danish Gold, C. I. No. 1391, Gond Gerst, C. I. No. 1393, Heil Hanna 3, C. I. No. 682, and Odessa, C. I. No. 961 were the most resistant, although not equaling varieties in *H. vulgare pallidum*. The few varieties in *H. deficiens* were all susceptible to both physiologic forms.

The varieties Apalan, C. I. No. 1347, Featherston, C. I. No. 1120, Leh, C. I. No. 700, Malting, C. I. No. 1129, Oderbrucker, C. I. Nos. 940 and 957, and Pannier, C. I. No. 1330, in *Hordeum vulgare pallidum*; Diana, C. I. No. 1345, Hooded Spring, C. I. No. 716, Horsford, C. I. Nos. 507, 610, and 877, Kipper, C. I. No. 1291, and McFadden, C. I. Nos. 1398, 1399, 1401, 1402, 1404, 1406, 1408, and 1409, in *H. vulgare horsfordianum*; McFadden, C. I. No. 1405, in *H. vulgare coeleste;* and McFadden, C. I. Nos. 1400, 1403, and 1407, in *H. distichon angustispicatum* were outstanding for difference in reaction to the two physiologic forms, being highly resistant to physiologic form 1 and highly susceptible to physiologic form 2.

After 1924 a selected series of varieties was studied for susceptibility under field conditions at La Fayette, Ind. Only a slight percentage of rust developed in 1925 and 1926, and it was impossible to draw conclusions concerning susceptibility. In 1927, 1928, and 1929 abundant rust developed. Marked differences between vari-

eties were noted. The varieties outstanding for their rust resistance are Abacus, C. I. No. 1088, Abyssinia, C. I. No. 2192, Abyssinian, C. I. No. 1243, Arequipa, C. I. Nos. 1256 and 2329, Bolivia, C. I. No. 1257, Cabeza, C. I. No. 1437, Callas, C. I. No. 2440, Chile, C. I. No. 663, Chile Brewing, C. I. No. 657, Coast, C. I. Nos. 276 and 690, Gehangir, C. I. No. 1089, Juliaca, C. I. No. 1114, Luth, C. I. No. 972, Maxima, C. I. No. 1436, Mecknos Moroc, C. I. No. 1379, Peru, C. I. No. 653, Peruvian, C. I. No. 935, Quinn, C. I. No. 1024, Tonot, C. I. No. 1012, Turkestan, C. I. No. 711, Weider, C. I. No. 1021, and an unnamed variety, C. I. No. 1383, in *Hordeum vulgare pallidum*, and Danish Gold, C. I. No. 1391, Gond Gerst, C. I. No. 1393, Heil Hanna 2, C. I. No. 678, and Heil Hanna 3, C. I. No. 682, in *H. distichon palmella.*

A number of varieties showed in their seedling stage considerable variation in reaction. This was specially noticeable in the reactions to physiologic form 1 of Chilean C, C. I. No. 1432, Chilean D, C. I. No. 1433, and Lynch, C. I. No. 919, which varied in reaction from 0 to 3+. Chile, C. I. No. 663, Chilga Arpa, C. I. No. 744, and Coast, C. I. No. 276, varied from 0 to 2+, while several others varied from 1 to 3, 2 to 4, etc. This probably is in correlation with environmental conditions, since such varieties showed the greatest resistance during the late fall and winter months, when light conditions were poor, and the most susceptibility in the late spring and early summer.

As can be seen by consulting Tables 1, 2, and 3, a number of varieties showed more or less resistance under all conditions. The varieties outstanding for resistance in the seedling stage to physiologic forms 1 and 2 and also for resistance in the field tests at La Fayette, Ind., are Abacus, C. I. No. 1088, Abyssinian, C. I. No. 1243, Callas, C. I. No. 2440, Chile, C. I. No. 663, Chile Brewing, C. I. No. 657, Coast, C. I. Nos. 276 and 690, Luth, C. I. No. 972, Mecknos Moroc, C. I. No. 1379, Quinn, C. I. No. 1024, Sulu, C. I. No. 1022, and Weider, C. I. No. 1021, belonging to *Hordeum vulgare pallidum;* Abyssinia, C. I. No. 2192, in *H. vulgare pallidum pyramidatum;* Arequipa, C. I. Nos. 1256 and 2329, Bolivia, C. I. No. 1257, and Juliaca, C. I. No. 1114, in *H. vulgare pallidum coerulescens;* Purple Nepal, C. I. No. 1373, in *H. vulgare trifurcatum;* and Danish Gold, C. I. No. 1391, Gond Gerst, C. I. No. 1393, and Heil Hanna 3, C. I. No. 682, in *H. distichon palmella nutans.* It is to be noted that 16 of these belong to *H. vulgare pallidum*, 1 to *H. vulgare trifurcatum*, and 3 to *H. distichon palmella.* Not only are there considerable differences within the botanical groups, but even within the agronomic varieties there are marked differences in reaction. Thus, Featherston, C. I. No. 1120, is very resistant to physiologic form 1, while Featherston, C. I. Nos. 911, 954, 1118, and 1119, are very susceptible. Oderbrucker, C. I. Nos. 940 and 957, are very resistant to physiologic form 1, while Oderbrucker, C. I. Nos. 969, 1137, and 1396, are very susceptible. Manchuria, C. I. No. 2330, is very resistant to physiologic form 1, while Manchuria, C. I. Nos. 1178 and 1435, are highly susceptible.

TABLE 3.—*Percentage of leaf rust of barley, Puccinia anomala, in field tests at La Fayette, Ind., 1927, 1928, and 1929* [1]

Variety	C. I. No.	Percentage of rust		
		1927	1928	1929
Hordeum vulgare pallidum:				
Abed July	1390			T-14
Abyssinia	949	25-49		
Do	950			25-49
Do	2380			75-99
Do	2410			50-74
Do	2418			75-100
Abyssinian	1223			50-74
Do	1228			50-64
Do	1243	T-4	0-4	0-14
Azov	1028			25-49
California Mariout	1455	50-64		
Callas	2440	0-T	0-T	0-T
Chevron	1111			25-34
Chile	663	0-T	0-4	
Chilga Arpa	744	50-64	T-14	50-64
Club Mariout	261	50-64		
Coast	276	0-T	0-T	
Do	690	T-4	0-T	
Do	691			50-64
Do	2369			50-64
Consul	1061			50-64
Daniels	971	50-64	50-74	50-64
Eagle	913	75-100	75-100	
Featherston	1118	25-34		
Do	1120	50-64	50-74	50-64
Fleche	1263			65-100
Gehangir	1089		T-4	
Kumflide	730			50-64
Kwan	1016	0-T		50-64
Leh	700	25-49	T-14	25-49
Luth	972	T-24	0-T	
Manchuria	244	75-100		
Manmoy	2456			50-64
Mecknos Moroc	1379	0	0-T	0-T
Mignon	999			50-64
Monte Cristo	1017			25-49
Nani Tal	1087			50-64
Oderbrucker	940	25-49	T-14	15-49
Do	957	25-34	0-T	
Do	1137			50-64
Odessa	916	50-64	T-14	
Pannier	1330	50-74		
Peru	653	T-14	0-T	
Peruvian	935	0-T	T-4	
Quinn	1024	0-T	0-T	0-4
Rubard	2434			50-64
Sulu	1022			T-4
Tonot	1012	T-4	0-T	
Trebi	936			75-100
Turkestan	711	T-4	0-T	
Unnamed	1383	5-14	0-T	
Weider	1021			T-14
White Gatami	920		25-49	50-64
Wisconsin Winter	519	50-64	50-74	
Hordeum vulgare pallidum pyramidatum:				
Abacus	1088			T-4
Abyssinia	2192	0	0-T	
Chile Brewing	657	0-T	0-14	0-T
Club Mariout	932	25-49		15-24
Czech	1023	15-24		
Malwet	2459			50-64
Mulyan	2453			65-100
Pasha	984			50-74
Pegan	2454			50-64
Welcome	2439			75-100
Hordeum vulgare pallidum rikotense:				
Catts	1283			50-64
Feline	1284			50-64
Hordeum vulgare pallidum rikotense—Contd.				
Gilette	1359			65-74
Jusborne	1355			75-100
Leader	1282			65-100
Lyman	1358			75-100
Minorca	1357			75-100
Norbec	1363			50-64
Plymoth	1356			50-64
Unnamed	1352			50-64
Do	1353			50-74
Vitz	1306			50-64
Hordeum vulgare pallidum coerulescens:				
Abyssinian	1235			65-100
Do	1242			75
Albacete	1128			25-49
Algerian	1179			15-24
Arequipa	1256	0	0-T	0-T
Do	2329			0-T
Barquis	1076	15-24	0-T	
Bolivia	1257	0	0-T	0-14
Do	1365			T-4
Cabeza	1437	0-T	0-T	T-14
Canadian Malting No. 2	1034			35-49
Cape	1386			50-64
Do	1431	15-24	25-34	
Coast	2332			50-64
Cromlech	1215			0-T
Crypt	1090			50-64
Cyma	1258			50-64
Juliaca	1114	0-T	0-T	
Kimberly	1382	T-14		
Lynch	919	T-4	0-T	25-34
Malting	1129	15-24	50-100	50-64
Maxima	1436	0-T	5-14	
Persia	1372			100
Peruvian	1131	0-T	50-64	0-14
Roseworthy Oregon	1439	15-34	T-14	
Squarehead Winter	1267			25-49
Tripoli	1115	25-49		
Hordeum vulgare pallidum subviolaceum: Soochow	867			65
Hordeum vulgare nigrum:				
Barbican	1265			25-49
Gatami	1413			50-64
Oswong	697	T-14		15-24
Hordeum vulgare nigrum leiorrhynchum:				
Black Algerian	708			50-74
Chorny	875			50-74
Lion	923			15-64
Nekludowi	1000			50-64
Hordeum vulgare horsfordianum:				
Hooded Spring	716	15-24		50-64
Horsford	507	25-34	50-100	35-49
Do	610	15-24	25-34	50-74
Do	877	25-49	50-100	
Do	2482			50-64
Kipper	1291			25-49
McFadden	1408	15-24	50-74	50-64
Do	1409	15-24	50-100	50-64
Hordeum vulgare coeleste:				
Debra	1085			74
Hansee Hull-less	703			65-74

[1] See footnotes *a*, *b*, and *c* to Table 1.

TABLE 3.—*Percentage of leaf rust of barley, Puccinia anomala, in field tests at La Fayette, Ind., 1927, 1928, and 1929*—Continued

Variety	C. I. No.	Percentage of rust		
		1927	1928	1929
Hordeum vulgare coeleste—Con.				
India	2319			100
Kharsila	733			50–74
Robin	991			50–64
Unnamed	671			50
Watho	2458			75–100
Hordeum vulgare coeleste himalayense:				
Ederle	1015			15
Himalaya	620			35–49
Do	1312			35–49
Hordeum vulgare coeleste violaceum:				
Black Hull-less	666			15–49
Spain	1370			25–49
Hordeum vulgare trifurcatum:				
Black Hull-less	1032			65–74
Lihor	866	50–64		
Nepal	247			50–64
Do	598	25–49		
Purple Nepal	1373	0	0	50–64
Hordeum intermedium haxtoni: Famesh	616			75–100
Hordeum intermedium haxtoni tonsum:				
Arlington Awnless	702	100	75–100	
Bodzu	753			50–74
Huwan	1080			100
Nakano Wase	754			75
Hordeum intermedium mortoni nigritonsum: Chinerme	1079			75–100
Hordeum intermedium cornutum: Cornutum	2366			100
Abyssinian Intermediate:				
Abyssinian Intermediate	2377			50–74
Do	2379			75–100
Do	2409			50–64
Black Abyssinian Intermediate	2416			50–74
Hordeum distichon palmella:				
Alpha	959		50–64	
Exedra	1262			T–74
Forsythe	2442			65–74
Norfut	1007			25–49
Odessa	961	0–T	5–14	50–64
Palestine	939	25–34		T–74
Pandora	1077			65–100
Pryor	2359	0	0–T	50–64
Hordeum distichon palmella nutans:				
Benito	1444			100
Chevalier	1245	75–100	75–100	65–100
Chevalier II	530	75–100	50–100	

Variety	C. I. No.	Percentage of rust		
		1927	1928	1929
Hordeum distichon palmella nutans—Con.				
Creel	1298			100
Danish Gold	1391	0–T	5–24	T–49
Eider	993	25–49	T–4	
Goldfoil	928	25–49		50–64
Gond Gerst	1393	0–T	5–14	T–34
Hanna	30	50–64	15–24	50–64
Do	203	50–64		
Do	906	50–100		50–74
Hannchen	602	100		
Heil Hanna 2	678	T–24	5–14	
Heil Hanna 3	682	0–T	0–T	
Moravian	965	75–100		
Princess	529			25–49
Proskowetz	893	15–24	0–T	
Pryor	1429	T–14		
Steigum	907	100	65–100	
Hordeum distichon palmella zeocriton: Fan	1381			50–74
Hordeum distichon palmella hypianthinum: Abyssinian	1239			50–74
Hordeum distichon palmella subviolaceum: Abyssinia	672			50
Hordeum distichon nigricans: Black Egyptian	1246			75–100
Hordeum distichon nigricans persicum: Erak	1003			T–14
Hordeum distichon angustispicatum:				
McFadden	1400			25–49
Do	1403			50–64
Hordeum distichon nudum:				
Crimean Hull-less	320			25–49
Gopal	1091			50–64
Milan	424			50–64
Poppenheim	314			15–24
Hordeum distichon nudumianthinum: Irisaka	1083			100
Hordeum distichon nigrinudum: Jet	967			100
Hordeum deficiens deficiens:				
Abyssinia	2376			50–100
Abyssinian	1225			25–49
Do	1236			25–49
Burley	1294			65–100
Claudia	1297			75–100
Redfield	1295			65–74
Unnamed	2325			50–64
Hordeum deficiens steudeli:				
Abyssinia	362			50–100
Blackhull	878	100	100	50–100

POWDERY MILDEW STUDIES

Studies on powdery mildew were made in a manner similar to those on leaf rust, except that no data were obtained in the field, since powdery mildew is not usually severe at La Fayette, Ind.

As has been reported elsewhere,[6] five physiologic forms of the powdery mildew of barley have been recognized in cooperative studies with the Iowa Agricultural Experiment Station. Of these, physiologic forms 1, 2, and 3 have been studied in the greenhouses of the Purdue University Agricultural Experiment Station on the barley varieties used in the leaf-rust investigations. The results of these studies are given in Table 4.

TABLE 4.—*Reaction of barley varieties to physiologic forms 1, 2, and 3 of the powdery mildew of barley (Erysiphe graminis hordei) in greenhouse studies in stated years* [a]

Variety	C. I. No.	Reaction to physiologic form [b]—					
		1		3		2	
		1924	1926	1927	1929	1929	1930
Hordeum vulgare pallidum:							
Abed July	1390	4			4	2+	2+
Abundio	1412	2					
Abyssinia	361	1			1		
Do	949	4		3-4	4	4	
Do	950	2			2	1	3
Do	951	3					
Do	2380	2				1+	
Do	2410	2		2	1	1—	
Do	2411	3		4	2+	2	
Do	2418	4				2	
Abyssinian	1216	2					
Do	1217a	4					
Do	1217b	3			4	4	4
Do	1218	4					
Do	1219	4					
Do	1221	4			3	4	
Do	1223	2			2	1	2+
Do	1226	1			2	3+	
Do	1227	1			T	3+	
Do	1228	3			1+	3+	2-3
Do	1231	2					
Do	1233	2			2+	2	
Do	1237	3					
Do	1241	2			2+	2	
Do	1243	1		0-1	1+	2	1
Acanthus	1095	4			4	4	
Alcazar	1096	4			4	4	
Alexis	968	4			4	3	
Amarillo	1073	1					
Apalan	1347	4		2-3	3	4	
Arabel	896	3					
Argentine	223	4					
Azov	1028	1			4	T	2
Baker	975	4			4	4	
Barbary	695	3			3	4	
Bashaw	1018	3			4	4	
Blue Ribbon	611	3	4	4	4	4	
Caballero	1006	4			4	4	
Cadmus	1054	1					
California Mariout	1455	3					
Callas	2440	3			2	3	
Canada Winter	713	1			2	2	
Canadian Lake Shore	2515	4			4	4	
Cape	557	3	2-3	3	2	4	
Do	1268	4			3	4	
Do	1387	4			4	3	
Carytid	1108	2					
Cebada	1055	2					
Chamnean	990	4			4	4	
Chelifl	1074	4			4	4	
Chevron	1111	0			0	0	0-1

[a] See footnotes *a* and *b* to Table 1.

[b] 0=Highly resistant, very slight development of mycelium accompanied by slight flecks or necrotic spots; 1=very resistant, slight development of mycelium and very slight sporulation; 2=moderately resistant, moderate development of mycelium and slight sporulation; 3=moderately susceptible, moderate development of mycelium and sporulation; 4=very susceptible, abundant development of mycelium and sporulation.

[6] MAINS, E. B., and DIETZ, S. M. PHYSIOLOGIC FORMS OF BARLEY MILDEW, ERYSIPHE GRAMINIS HORDEI MARCHAL. Phytopathology 20:229-239, illus. 1930.

TABLE 4.—*Reaction of barley varieties to physiologic forms 1, 2, and 3 of the powdery mildew of barley (Erysiphe graminis hordei) in greenhouse studies in stated years*—Continued

Variety	C. I. No.	Reaction to physiologic form—					
		1		3		2	
		1924	1926	1927	1929	1929	1930
Hordeum vulgare pallidum—Continued.							
Chile	663	1	0–1	0–1	2+	1+	1–2
Chilga Arpa	744	4		3–4	3	4	
Clancy	1002	4			0+	3+	3–4
Club Mariout	261	4	3	4	2–3	3–4	
Coast	276	1	0–1	0–1	1	1–2	1–3
Do	626	3				3	4
Do	690	3		2–4	2+	3+	2–3
Do	691	2			4−	1+	2
Do	2369	2			2+	1	1+
Consul	1061	1		1	0	1	0+
Cortile	1123	4			3	4	
Crocket	1094	4			4	4	
Cusado	895	3			0–2	3+	
Czar	1005	2–4					
Daniels	971	4		3	4	3	
Dinar	729	4			4	3	
Duplex	2433	0		T–1	0	0	0
Eagle	913	3	4	4	2	3	3
Do	1300	3	3–4	2–3	3	4	
Do	1324	4	4	2–3	4	4	
Featherston	911	4	3	4	2+	4	
Do	954	4	3–4	4	4	4	
Do	1118	4		3–4	4	4	
Do	1119		3–4	3	4	3	
Do	1120	3	3–4	3–4	4	4	3–4
Fengsein	1040	1					
Finland	581	4			3	4	
Fleche	1263	0			T	0	0
Galwan	2348	2			2+	3	
Gehangir	1089	1		1	0	1+	
Gobi	1058	1				2+	
Greece	221	1					
Gurov	1099	4			2	2	
Han River	206a	4			3	4	
Do	206b	4					
Harem	1019	4			4	4	
Haua	734	3			3	4	
Hidalgo	1020	4					
Hisein	1053	2		2	0+	2	
Hodge	982	4			3	4	
Judith	1038	1					
July	1082	3			3	4	
Kaosein	1042	1					
Khanaka	743	4			3	4	
Khartum	2367	4		2–3	2	2	
Kopeck	869	2			3	2+	
Korsbyg	918	4		4	3+	4	
Kumflide	730	2			T	2	3
Kunshan	1065	1					
Kusan	1315	3			3–4	3	
Kwan	1016	0		T–1	0	0	
Ladrone	696	4		3	2+	4	
Lake City	1126	4			4	4	
Large-Grained Winter	408	3			2+	4	
Leh	700	2		2	2	2	
Liland	1323	4			4	4	
Loscin	1070	1			4	3	
Lubin	2435	4			4	2+	
Luth	908	4					
Do	972	1		0–1	3	T–1	1
Malster	1025	4			4	4	
Mammoth Winter	220	3					
Manchuria	244	4	3–4	3	2+	3–4	
Do	354	4	3–4	4	3	4	
Do	576	4			2+	4	
Do	643	4	3–4	4	4	4	
Do	956	4	3–4	3	4	4	
Do	1251	4	3–4	4	4	4	
Do	1397	4	3	4	4	4	
Manchuria Pedigree	1244	3	3	2–3	3	4	
Manmoy	2456	1			4	1	2
Mecca	1051	1					

TABLE 4.—*Reaction of barley varieties to physiologic forms 1, 2, and 3 of the powdery mildew of barley (Erysiphe graminis hordei) in greenhouse studies in stated years*—Continued

Variety	C. I. No.	Reaction to physiologic form—					
		1		3		2	
		1924	1926	1927	1929	1929	1930
Hordeum vulgare pallidum—Continued.							
Mecknos Moroc	1379	2		2–3	1+	3	
Michung	1160	4			3	4	
Mignon	999	4			2+	2	
Monte Cristo	1017	0			0–7	0	0
Nani Tal	1087	1			1	1	0–1
Nanook	1329	2			2	2+	
Niver	737	1				1	
Notherson	1093	4			4	4	
Oderbrucker	940	4	3–4	4	4	4	4
Do	957	4	2–4	3	4	4	
Do	969	4	4	3	3–4	4	
Do	1137	4	3–4	4	4	4	
Do	1396	3	4	4	4	4	
Odessa	182	3	4	4	4	4	4
Do	916	4		4	3–4	3	
Do	927	4	4	4	4	4	
Do	934	4	3	3	3	4	
Do	974	4	4	3	4	4	
Olonets	19[illegible]	4			4	4	
Pannier	1330	2		2	4	3+	
Peru	653	1	1	0–2	1+	1–2	1–2
Peruvian	935	1	1	0–1	3–4	1	1
Petchora	2425	3–4			4	4	
Pidor	901	0					
Poda	652	1	1–2	1–2	2–3	2+	
Pontius	731	0		1–2	2	2	
Quinn	1024	3		2	2+	3+	4
Rasput	996	3			4	4	
Red River	973	4	3	4	4	4	
Rival	2345	4			3	4	
Royal	1252	4			4	4	
Rubard	2434	2			0–1	1	
Ruble	870	4			4	3+	
Sagina	1269	4				4	
Salamanca	689	3			3	3	
Sandrel	937	4	3–4	3	3	4	
Scottish Pearl	277	4					
Servian	915	4			4	4	
Shale	2430	4			3	2+	
Shorthead	2364	4			4	4	
Silver King	2374	3			4	4	
Squarehead Winter	252	2					
Sultan	997	2			4	3+	
Sulu	1022	1			0	0	1
Summit	929	4			4		
Do	1136	4			4	4	
Sumson	1092	4			4	4	
Surprise	171	4			4	4	
Telli	194	4	3–4				
Tenkow	646	3	2–3	3	3	4	
Tennessee Winter	257	3					
Do	876	3					
Texas Winter	554	4					
Tonot	1012	2		1–2	2	1+	
Trebi	936	4			4	2+	
Turkestan	711	1		0–1	2–3	T–1	1
Tystofte	1322	3					
Unnamed	497	2			4	4	
Do	1383	4		3–4	2+	3	
Do	2346	3			3+	4	
Do	2350	1					
Do	2368	2			4	3	1
Do	2371	4			3	4	
Do	2372	2–3			3	4	
Do	2373	4			4	4	
Do	2420	4					
Venus	736	1				2	
Victor	1411	2					
Wansnipe	1050	2					
Weider	1021	1		0–1	0	0	0–1
White Gatami	920	1	T–1		0–1	1+	1
White Russian	706	3					

TABLE 4.—*Reaction of barley varieties to physiologic forms 1, 2, and 3 of the powdery mildew of barley (Erysiphe graminis hordei) in greenhouse studies in stated years*—Continued

Variety	C. I. No.	Reaction to physiologic form—					
		1		3		2	
		1924	1926	1927	1929	1929	1930
Hordeum vulgare pallidum—Continued.							
Winter	667	0			3	4	
Wisconsin Winter	519	2	1	1	1–4	1–2	3
Woodrow	986	3	1	1	4	4	
Wusein	1044	1			2	2+	
Youshan	1068	2		3	2+	2+	
Yuwan	1071	1			3	3+	
Zond	1138	3			4	3	
Hordeum vulgare pallidum parallelum:							
Abyssinia	943	3			3	4	
Do	946	4					
Abyssinian	2193	2					
Gambrinus	1066	2					
Hordeum vulgare pallidum pyramidatum:							
Abacus	1088	1–0			1	0	
Abyssinia	2192	2		1	1	1	
Abyssinian	2194	1					
Do	2195	2				2	
Chile Brewing	657	1	T–1	1	1+	1–2	
Club Mariout	932	3	3–4	2	1+	3+	4
Do	2334	3			4	3	
Czech	1023	3		3	3–4	3	
Filer	1059	1					
Kobeck	2436	3			3	2+	
Lochink	2460	0		1	3	3	
Malwet	2459	0			0–1	T	0–1
Moy Wah	1064	1					
Mulyan	2453	0			1	1	0
Pasha	984	1			T	0	0–2
Pegan	2454	0			0	0	0
Russia	1371	3			3	3+	
Scarab	995	4		3	2+	4	
Welcome	2439	1			1	0	2
Winter Club	592	3					
Hordeum vulgare pallidum rikotense:							
Andrew	1351	3			2–3	4	
Blarney	1303	3			2+	2+	
Catts	1283	2			2	2	
Cheddar	1307	2			3	2+	
Coates	1349	2			2+	2	
Feline	1284	2			1+	2+	1+
Fergel	1360	2			2	2+	
Gilette	1359	1			2	2+	
Hero	1286	3			3	3	1
Heron	1299	3			3+	3+	
Hopper	1285	4			3	4	
Hurst	1304	4			4	4	
Jusborne	1355	1				1+	1+
Lariout	1350	3			3	4	
Leader	1282	2			2	2	
Limerick	1302	3		2	2–3	3	
Louden	1308	4			3	4	
Lyman	1358	2				1	2
Minorca	1357	3			2	1	1
Morrison	1361	2			2	2	
Newcomb	1368	2			1+	2	
Nigger	1301	3			2+	2+	
Norbec	1363	2			2+	1+	2
Olman	1354	3			2+	2	
Osborn	1364	3			3	3	
Phoebe	1305	2			2	4	
Plymoth	1356	2			2+	1+	2
Preston	1348	4			4	3+	
Ramsey	1366	2			2	2	
Theodore	1300	2			2+	3	
Unnamed	1352	3			2	1+	1+
Do	1353	3		2–3	2	1+	2–3
Do	2331	2–4			2–3	3	
Vaughn	1367	2			3	2+	
Vitz	1306	2			1	2	2
Hordeum vulgare pallidum coerulescens:							
Abyssinian	1235	2			1+	T	
Do	1242	2			1+		
Albacete	1128	1			0	T	1–2

TABLE 4.—*Reaction of barley varieties to physiologic forms 1, 2, and 3 of the powdery mildew of barley (Erysiphe graminis hordei) in greenhouse studies in stated years*—Continued

Variety	C. I. No.	Reaction to physiologic form—					
		1		3		2	
		1924	1926	1927	1929	1929	1930
Hordeum vulgare pallidum coerulescens—Continued.							
Algerian	1179	0			0	0	0
Arequipa	1256	2		0–2	3–4	1	1–2
Do	2329	1		0–1	2	1–	1
Barquis	1076	3		2–3	2+	3	
Blubak	2445	3			2–3	4	
Bolivia	1257	1	0–1	0–1	1+	1	1
Do	1365	4			2	1	2
Brutus	1011	3			4		
Buchiang	1043	2					
Cabeza	1437	2		1–2	1	1+	
Canadian Malting No. 2	1034	1			4	1	3
Cape	1026	4			4	2+	
Do	1386	4			4	1	2
Do	1431	3		2	2+	2+	
Cartouch	1107	4					
Chilean C	1432	0	0–1		1+	1+	1–2
Chilean D	1433	1		0–1	1	1	1
Coast	1430	3			2	4	
Do	2332	1			4	1	2+
Do	2333	1			4	4	
Do	2335	4		3	4	4	
Colorado	1075	2					
Coventry	1037	2			1	4	2
Cromlech	1215	2			2	1	3
Cyma	1258	3					
Juliaca	1114	2		2–3	1+	2+	1–2
Kimberly	1382	1		1	2+	1	
Koran	1063	1					
Lynch	919	1	1	0–1	4	T–1	1
Malting	1129	4	3	3	4	3	4
Manchuria	1178		3	2–3	4	4	
Do	1435	4	4	4	4	4	
Do	2330	4		3–4	4	4	
Maxima	1436	4		4	4	3	
Moldavia	392	4			2+	4	
Norton	1362	4			4	3+	
Oderbrucker	1174	3	4	3–4	4	4	
Odessa	1438	4	4	3	4	4	
Persia	1372	1			2+	1	1+
Peru	707	3	1				
Peruvian	1131	1		0–1	2+	T–1	1
Petro	994	3			2+	2+	
Roseworthy	2362			2–3	4	4	
Roseworthy Oregon	1439	3		3	3	2	
Sabbaton	1266	0					
Sanook	1395	2			3	2	
Shorthead	1441	4			4	3	
Squarehead	1417	4		3	4	4	
Squarehead Winter	1267	2			3	1	1+
Tripoli	1115	4		2–3	4	3	
Turbat	1254	3			3	4	
Wanfat	2461	1					
Hordeum vulgare pallidum subviolaceum:							
Abyssinian	1238	1			1	2+	
Chusein	1039	2					
Coolie	1060	2					
Envoy	1045	2					
Fesan	2463	2					
Hiangshan	1047	4					
Misein	1062	2					
Soochow	867	1				T	1
Squiers	1072	1					
Yatlong	2464	3					
Hordeum vulgare pallidum eurylepis:							
Ederle	1015	0			0	0	
Himalaya	1312	1			2+		
Do	2448	4			3+		
Wansnipe	2356	0					
Hordeum vulgare nigrum:							
Abyssinian	1220	0					
Do	1222	3					
Do	1230	2					
Do	1232	1					

TABLE 4.—*Reaction of barley varieties to physiologic forms 1, 2, and 3 of the powdery mildew of barley (Erysiphe graminis hordei) in greenhouse studies in stated years*—Continued

Variety	C. I. No.	Reaction to physiologic form—					
		1		3		2	
		1924	1926	1927	1929	1929	1930
Hordeum vulgare nigrum—Continued.							
Barbican	1265	1			T	0	0–1
Do	2336	1			0	0	
Black Russian	705	2					
Donjon	1264	0					
Gatami	575	2	1–2	1–2	2	3	2–3
Do	1413	1	2	2–3			
Ghest	979	4					
Oswong	697	1		1	3–4	3	3
Unnamed	2349	0					
Wofut	1009	0					
Hordeum vulgare nigrum leiorrhynchum:							
Black Algerian	708	2			1	1+	
Chorny	875	1			1	1+	
Lion	923	1			1+	1+	2
Nekludowi	1000	1			1	1	0–1
Hordeum vulgare horsfordianum:							
Diana	1345	4			3+	4	
Hooded Spring	716	3	4	3–4	4	3–4	4
Horsford	507	3	3–4	3	4	4	
Do	610	4	3–4	3	3+	4	
Do	877	4	3–4	3	4	3	4
Do	1375	3	3–4	3	3	2+	3
Do	2324	1			2	2	2
Do	2482	2			4	1+	2+
Kipper	1291	4		3–4	3	4	
McFadden	1398	3		2–3	3	3	
Do	1399	4		3	3	4	
Do	1401	4		4	4	4	
Do	1402	4		4	3	4	
Do	1404	4		2–3	3	4	
Do	1406	4			4	4	
Do	1408	4		2–3		2+	
Do	1409	4		3	4	2+	
Nuerta	741	1					
Sirroche	1289	1			3	4	
Wilder	1346	4			4	4	
Hordeum vulgare coeleste:							
Ak Arpa	747	4		3	4	4	
Barley Wheat	1384	2			4	4	
Black Hull-less	735	3			3	4	
Do	1097	4	3	2	4	4	
Chilga Arpa	2351	4			4	4	
Comju	2358	3					
Dehra	1085	0			1	4	
Eremo	1014	2					
Galangatch	727	3					
Gorak	1086	3			4	4	
Hankow	197	1					
Hansee Hull-less	703	3	1–3	2			
Himalaya	254	2	2	2	2–3	3–4	2–3
Hull-less	745	3	2–3	2–3	3+	3	
Do	699	4		2–3	3+	3+	
Huskless	722	3					
India	698	3			3		
Do	2318	1			2		
Do	2319	1			0–1	2	
Iris	998	0					
Ivory	865	4		3–4	4	4	
Kama-orc	694	2			2	2	
Kharsila	733	0		0	0	0	
Kok Arpa	746	1			4	3+	
Maynang	2429	1					
McFadden	1405	4					
Memesh	593	2					
Orkoe	2465	3					
Pingpong	1056	3					
Pingyan	1067	4		3	4	3	
Poree	2428	1					
Robin	991	2			T	T	
Saggia	1316	2			2+	3+	
Sangatsuka	78	3	1–2	3	4	4	
Santizo	1049	1					

TABLE 4.—*Reaction of barley varieties to physiologic forms 1, 2, and 3 of the powdery mildew of barley (Erysiphe graminis hordei) in greenhouse studies in stated years*—Continued

Variety	C. I. No.	Reaction to physiologic form—					
		1		3		2	
		1924	1926	1927	1929	1929	1930
Hordeum vulgare coeleste—Continued.							
Semet	1314	1			2+	3	
Swedish Hull-less	623	3			2+	4	
Tatien	665	4			3	4	
Thomas	1041	3				4	
Unnamed	671	1			1		3
Watho	2458	1			0-1	1	1
Yanehadaka	580	3			3	3	
Zunpakei	692	1		2		3	
Hordeum vulgare coeleste himalayense: Himalaya	620	1	2-3	2	3-4	3	
Hordeum vulgare coeleste nudipyramidatum:							
Black Hull-less	596	3	2-3	2-3	3+	3	
Do	618	4	3	3	2+	4	
Do	666	1	2	0-2	3+	1-2	2
Do	1027	4					
Do	2320	3			2-3	3	
Do	2449	4				3	
Kamamugi	577	3			2	3+	
Mochi-Hadaka	2423	2					
Do	2424	2					
Purple Hull-less	1415	4			4	4	
Spain	1370	2			3+	1+	2+
Taihu	868	1					
Tanbash	578	4			4	3+	
Hordeum vulgare trifurcatum:							
Black Hull-less	1032	1	2	1-2	3+	3+	2-3
Lihor	866	0		0-2	2-3	2	2-3
Nepal	247	1	2-3	4	4-	4	
Do	250	1	2	3		4	
Do	262	1		4	2	4	
Do	475	1	2	2-3	4	4	3-4
Do	489	1	2	2-3			
Do	533	2	2-3	3-4	3	4	
Do	595	1	2	1	4	4	3-4
Do	598	1	3	1	3	4	
Do	1290	1	3	2	3	3	
Do	1292	1	3	2	3	3	
Do	1385	4	2	3-4	3	4	
Do	2322	1			3+	4	
Purple Nepal	1373	1		1-2	4	3+	3-4
Skinless	1414	1			4	3	
Subnepal	2321	1				2-3	
Hordeum intermedium haxtoni: Famesh	616	1				T	0
Hordeum intermedium haxtoni tonsum:							
Arlington Awnless	702	0	0	0	0	0	0
Bodzu	753	1			1	3	3
Bozu	749	2					
Huwan	1080	0		0	0	1+	0-1
McFadden	1443	3			3	3	
Nakano Wase	754	1	1		4		
Saitama-Nishiki	752	1					
Hordeum intermedium mortoni nigritonsum:							
Chinerme	1079	0			1	T	0
Nigrate	2444	0		0	0-1	0	0
Hordeum intermedium nudihaxtoni: Unnamed	2352	1			4	4	
Hordeum intermedium cornutum:							
Cornutum	1317	4			4	4	
Do	2366	1			4	4	
Nepaul	724	2	2-3	2	3-4	2+	
Abyssinia Intermediate:							
Abyssinia	676	2			2+		
Abyssinian Intermediate	2326	4			4	4	
Do	2377	1				1+	
Do	2379	1				1+	
Do	2381	3			3+	3+	
Do	2382	3			3	3	
Do	2407	3					
Do	2409	1				1+	
Do	2415	3		3-4	4	3	
Do	2514	4			3-4	3+	
Black Abyssinian	2383	2			3	4	
Black Abyssinian Intermediate	2416	1		1	1+	1+	1-2
Mandarin	981	1					

TABLE 4.—*Reaction of barley varieties to physiologic forms 1, 2, and 3 of the powdery mildew of barley (Erysiphe graminis hordei) in greenhouse studies in stated years*—Continued

Variety	C. I. No.	Reaction to physiologic form—					
		1		3		2	
		1924	1926	1927	1929	1929	1930
Hordeum distichon palmella:							
Alpha	959	4			3	4	
Archer	2360	4			4	4	
Bolton	177	4			3	4	
Do	922	3			4	2	
Cleroff	985	4					
Ernest	2443	2					
Exedra	1262	0			0	0	1+
Fidel	1445	4			4	3+	
Forsythe	2442	2				2	
Golden Grain	2363	4				4	
Goldthorpe	1424	4	3	3	4	4	
Hanchamont	1121	4			4	3+	
Khayyam	1117	1					
Kinver	2361	4			3	4	
Newbly	2437	4			4	4	
Norfut	1007	1			4	0	2
Odessa	961	4	4	4	3	4	
Omar	898	4			4	4	4
Orel	351	3			4	4	
Palestine	939	2		0–2	1	1	0–1
Pandora	1077	1			1	4	
Pasvolski	1103	4			4	2	
Pryor	2359	4		2–3	4	3	
Rex	1388	4			4	4	
Roshal	1344	4			3+	4	
Semir	1255	4			4	4	
Shale	988	2			4	4	
Shiraz	1078	1					
Silesia	978	4					
Svanson	1342	4			2+	4	
Syria	1259	1	1			1+	
Theda	1293	4			3	3+	
White Smyrna	658	2			4–	4	
Hordeum distichon palmella nutans:							
Abed	1389	4		3–4	4	4	
Abed Binder	1081	4			4	4	
Do	2446	4			4	4	
Do	2447	4			4	3+	
Abyssinia	355	4			4	4	
Abyssinian	1229	4			2+	2	
Do	1234	4			4	4	
Archer	1418	4		4	4	4	
Australian White	925	4			4	3	
Bander	2354	4			4	4	
Bema	1100	4			4	4	
Benito	1444	3			3+	3+	
Benny	1288	4			4	4	
Bohemian	32	4	3–4	2–3	3	4	
Do	204	4	4	4	4	4	4
Do	933	4	3	2	2	4	
Do	1148	4	4	4	4	4	
Broach	1101	4			4	4	
Calotte	1102	4			4	4	
Canadian Battledore No. 1	1033	4			4		
Caucasian	714	3			4	4	
Chalet	1110	4			4	4	
Chevalier	156	4	4		2	4	
Do	278	4	3	4	2+	3–4	
Do	1419	4	3	3	3	4	
Do	2317		3–4	2–3	4	4	
Do	2375	4			4	4	
Chevalier II	530	3	3–4	4	4	4	
Creel	1298	2			2	1+	
Danish Gold	1391	3		2	3	4	
Eider	993	4		3	3–4	4	
Franconian	679	4			3	4	
Do	680	4					
Frankish	953	4			4	3	
Gisborne	1030	3			4	4	
Gold	1145	4			4	4	
Goldfoil	928	0	0	0	0	0	0
Goldthorpe	2357	3			4	4	

TABLE 4.—*Reaction of barley varieties to physiologic forms 1, 2, and 3 of the powdery mildew of barley (Erysiphe graminis hordei) in greenhouse studies in stated years*—Continued

Variety	C. I. No.	Reaction to physiologic form—					
		1		3		2	
		1924	1926	1927	1929	1929	1930
Hordeum distichon palmella nutans—Contd.							
Gond Gerst	1393	3		2	4	3	
Hanna	24	4		4	4	4	
Do	30	2		1	1−	1+	
Do	34	4		4	4	4	
Do	203	4	3	4	3	4	
Do	906	0	0	0	0	0	0
Do	942	4	3		4	4	
Do	966	2	1	1–2	3	1	1+
Do	1122	4	3–4	3	4	4	
Hannchen	531	3	3	3	2+	3–4	
Do	602	4	4	3	4	4	
Do	1425	4	3	2	3	4	
Heil Hanna 1	681	4	3–4	3–4	3	4	
Heil Hanna 2	678	4	3–4	3–4	2	3+	
Heil Hanna 3	682	1	1–2	2–3	4	4	3–4
Horn	926	4	3–4	4	4	3	
Italian	914	4					
Kinver	1029	4			3+	4	
Do	1434	3			4	4	
Kinver Chevalier	587	4	3–4	3	4	4	
Kirgiz	1253	4			4	4	
Kirgizean	1426	3			3+	4	
Kite	992	4			3	4	
Kitzing	189	3			2–3	3+	
Kolter	987	4					
Kurall	2450	3			3–4	3+	
Kurof	1098	4			3	4	
Lonhals	1343	4			3	4	
Mahrische	912	3	4	1–2	2	1+	2+
Moravian	965	3	1	0	2+	2	
Nesbit	2451	4			3–4	3+	
Paulina	963	4			3	4	
Prentice	917	3			4	4	
Pride of Dakota	218	4			4	4	
Princess	529	4	4	4	4	4	
Do	603	4	3–4	3–4	3–4	4	
Do	1428	4	3–4	4	4	4	
Proskowetz	893	3	3	3	3–4	4	
Pryor	1429	4		4	2+	4	
Sealand Prentice	1392	4			4	4	
Selco	2452	4			3+	4	
Shale	2431	4			4	4	
Steigum	907	4	4	3	4	4	
Do	931	4	3–4	3	3	4	
Striegum	47	4	4		2	4	
Surprise × Primus	1124	3–4				4	
Tivannes	1109	4			4	4	
White Moravian	977	4			4	3+	
White Smyrna	195	4					
Wibley	2438	4		4	4	4	
Zero	1287	4			4	4	
Hordeum distichon palmella erectum:							
Anthony	1341	3			4	4	
Archer	1031	4		4	4	4	
Canadian Thorpe	740	4			4	4	
Duckbill	1420	4			4	4	
Garton 986	645	4			4	4	
Garton Regenerated Malster	1421	4			4	4	
Gisborne	1422	4			4	3	
Golden Grain	1423	4			4	3+	
Golden Melon	958	4			4	3	
Goldthorpe	1340	4	3–4	3–4		4	
Imperial	617	4			3	4	
Invincible	590	4					
Nesbian	647	3	2–3	3	1+	4	
Pickett	1004	4			4	4	
Primus	532	4				4	
Do	1427	4	3	3–4	4	4	
Svanhals	187	4	3–4	4	3	4	
Tanchang	1164	4			3	4	
Thorpe	921	4					
Unnamed	2355	4			3+	4	
Do	2370	4			4	4	

TABLE 4.—*Reaction of barley varieties to physiologic forms 1, 2, and 3 of the powdery mildew of barley (Erysiphe graminis hordei) in greenhouse studies in stated years*—Continued

Variety	C. I. No.	Reaction to physiologic form—					
		1		3		2	
		1924	1926	1927	1929	1929	1930
Hordeum distichon palmella zeocriton:							
Fan	1380	2			3+	4	
Do	1381	3				1+	2
Hordeum distichon palmella hypianthinum:							
Abyssinian	1239	1			2	2	
Hordeum distichon palmella subviolaceum:							
Abyssinia	672	2			1	1	
Hordeum distichon nigricans:							
Black Arabian	202	4	3–4				
Black Egyptian	1246	1			1	0	0–2
Black Smyrna	191	4			3–4	4	
Caliph	983	0					
Dentil	1260	2					
Hordeum distichon nigricans persicum: Erak	1003	2			1+	1+	2+
Hordeum distichon angustispicatum:							
Childs	1326	4			4	4	
McFadden	1400	4		4			
Do	1403	4		2–3	4	3+	
Do	1407	4		4	4	4	
Hordeum distichon nudum:							
Baku	253	3		3–4	1+	1	2
Do	709	1					
Crimean Hull-less	320	2			1	1	2
Evans	621	2	1–2	1–2	2–3	2	
Gopal	1091	1			0	0	
Mesa	2327	2			3	2+	
Milan	424	2			1	1+	2
Poppenheim	314	4			1	2+	3
Swedish Hull-less	2512	2			3	4	
Hordeum distichon nudumianthinum: Irisaka	1083	0			0	0	
Hordeum distichon nigrinudum: Jet	967	1			T	T	
Hordeum deficiens deficiens:							
Abyssinia	2376	1			2	1+	2+
Abyssinian	1224	2			2	2	
Do	1225	3		1–2	2+	1	2–3
Do	1236	2			2	1	2+
Do	1240	2			2	2	
Burley	1294	2			2	2	
Claudia	1297	3					
Deficiens	2325	2			2	1+	
Kitchin	1296	4			3	4	
Redfield	1295	3			2+	2+	
Hordeum deficiens steudeli:							
Abyssinia	362	2		1–2	1	1+	1
Blackhull	878	2	0–1	1	4	1	1
Hordeum deficiens nudideficiens: Buland	1084	4			4	4	

From Table 4 it is evident that resistance to powdery mildew physiologic form 1 is not limited to any particular group of barley varieties but is to be found throughout various types. It is evident also that different strains of the same variety may differ considerably in reaction. This is best shown in the variety Hanna; the strains C. I. Nos. 24, 203, 942, and 1122 were all found to be more or less susceptible, whereas the strains C. I. Nos. 30 and 966 were more or less resistant. The strain C. I. No. 906 was outstanding for very marked resistance, type 0.

Physiologic forms 2 and 3 were tested on a restricted series of varieties. As shown in Table 4, fewer varieties were resistant to these physiologic forms. As with physiologic form 1, there was considerable variation in type and stability of reaction. A number of varieties, however, showed considerable resistance to all three forms.

DISCUSSION

It is evident that resistance to the various physiologic forms of the leaf rust and powdery mildews of barley is rather widely scattered throughout the barley groups. The varieties differ considerably, not only in the type of reaction but also in stability of reaction. Some show uniformly a marked resistance, whereas others fluctuate considerably in type of reaction.

On the other hand, such varieties as Chilean C, C. I. No. 1432, Chilean D, C. I. No. 1433, and Lynch, C. I. No. 919, varied considerably in reaction, being sometimes classified as highly resistant and at other times moderately susceptible. There is some evidence that these fluctuations are correlated with environmental changes, the varieties being more susceptible under high-light intensities and temperatures. Waterhouse[7] has noted marked differences of this nature in his studies in Australia.

Varieties also differed considerably in relative reaction in the greenhouse and in the field. Some varieties, such as strains of Horsford, when inoculated in the seedling stage in the greenhouse with physiologic form 1, were more resistant than when infected with the same form in the field in the head stage. (Table 1.) On the other hand, a number of varieties were more resistant in the field than in the greenhouse.

Not only are the barley varieties differentiated for distinguishing physiologic forms of the rust but physiologic forms of the rust may differentiate between very similar types of barley. Thus Featherston, C. I. No. 1120, is very resistant to physiologic form 1, while the Featherston strains, C. I. Nos. 911, 954, 1118, and 1119, are very susceptible. In Oderbrucker, strains C. I. Nos. 940 and 957 are very resistant, while strains C. I. Nos. 969, 1137, and 1396 are very susceptible.

Similar differences occurred in regard to reaction to powdery mildew. In the seedling stage a number of varieties are very susceptible to all the physiologic forms. Such varieties as Lynch, C. I. No. 919, and Peruvian, C. I. No. 935, are highly resistant to some of the physiologic forms and very susceptible to others. Some, such as Hansee Hull-less, C. I. No. 703, Nepal, C. I. Nos. 489 and 1385, and Pryor, C. I. No. 2359, varied considerably in reaction to a physiologic form. Such varieties as Arlington Awnless, C. I. No. 702, Bolivia, C. I. No. 1257, Chilean D, C. I. No. 1433, Duplex, C. I. No. 2433, Goldfoil, C. I. No. 928, Hanna, C. I. No. 906, and Kwan, C. I. No. 1016, showed remarkably uniform high resistance to all the physiologic forms used in these studies. As has been shown elsewhere,[8] Arlington Awnless, C. I. No. 702, Duplex, C. I. No. 2433, and Nigrate, C. I. No. 2444, are outstanding for their high resistance to all five of the physiologic forms thus far distinguished.

A number of varieties have shown resistance to both leaf rust and mildew. These include such varieties as Abacus, C. I. No. 1088, Abyssinia, C. I. No. 2192, Abyssinian, C. I. No. 1243, Arequipa, C. I. No. 2329, Chile, C. I. No. 663, Chile Brewing, C. I. No. 657, Chilean D, C. I. No. 1433, Coast, C. I. No. 276, Juliaca, C. I. No. 1114, and Kwan, C. I. No. 1016. The three varieties, Bolivia, C. I. No. 1257,

[7] WATERHOUSE, W. L. AUSTRALIAN RUST STUDIES I. Linn. Soc. N. S. Wales, Proc. 54: 615-680. 1929.
[8] MAINS, E. B., and DIETZ, S. M. Op. cit. See footnote 6.

Sulu, C. I. No. 1022, and Weider, C. I. No. 1021, are outstanding for resistance to the physiologic forms of both rust and mildew used in these studies.

SUMMARY

Barley varieties differ considerably in their reaction to leaf rust. Resistant varieties were found scattered throughout most of the barley groups. These differed in their type and stability of reaction.

Some varieties differed radically in their reaction to the two physiologic forms of leaf rust, being resistant to physiologic form 1 and susceptible to physiologic form 2. These include the varieties Featherston, C. I. No. 1120, Hooded Spring, C. I. No. 716, Horsford, C. I. Nos. 507 and 877, Malting, C. I. No. 1129, Manchuria, C. I. No. 2330, and Oderbrucker, C. I. Nos. 940 and 957.

The varieties Abacus, C. I. No. 1088, Abyssinia, C. I. No. 2192, Abyssinian, C. I. No. 1243, Arequipa, C. I. Nos. 1256 and 2329, Bolivia, C. I. No. 1257, Callas, C. I. No. 2440, Chile, C. I. No. 663, Chile Brewing, C. I. No. 657, Coast, C. I. Nos. 276 and 690, Danish Gold, C. I. No. 1391, Gond Gerst, C. I. No. 1393, Heil Hanna 3, C. I. No. 682, Juliaca, C. I. No. 1114, Luth, C. I. No. 972, Mecknos Moroc, C. I. No. 1379, Purple Nepal, C. I. No. 1373, Quinn, C. I. No. 1024, and Weider, C. I. No. 1021, showed marked resistance to both physiologic forms.

The varieties also differed considerably in their reaction to powdery mildew, showing differences in type and stability of reaction and marked differences in some cases to the three physiologic forms of mildew studied. Among others, the varieties Arequipa, C. I. No. 1256, Blackhull, C. I. No. 878, Lynch, C. I. No. 919, Oderbrucker, C. I. No. 940, and Peruvian, C. I. No. 935, showed marked differences in reaction to the physiologic forms included in these studies.

The following varieties were very resistant to physiologic forms 1, 2, and 3 of the mildew:

Abacus, C. I. No. 1088, Algerian, C. I. No. 1179, Arlington Awnless, C. I. No. 702, Barbican, C. I. Nos. 1265 and 2336, Black Egyptian, C. I. No. 1246, Bolivia, C. I. No. 1257, Chevron, C. I. No. 1111, Chilean D, C. I. No. 1433, Chinerme, C. I. No. 1079, Chorny, C. I. No. 875, Consul, C. I. No. 1061, Duplex, C. I. No. 2433, Ederle, C. I. No. 1015, Exedra, C. I. No. 1262, Fleche, C. I. No. 1263, Gehangir, C. I. No. 1089, Goldfoil, C. I. No. 928, Gopal, C. I. No. 1091, Hanna, C. I. No. 906, Huwan, C. I. No. 1080, Irisaka, C. I. No. 1083, Kharsila, C. I. No. 733, Kwan, C. I. No. 1016, Malwet, C. I. No. 2459, Monte Cristo, C. I. No. 1017, Mulyan, C. I. No. 2453, Nani Tal, C. I. No. 1087, Nekludowi, C. I. No. 1000, Nigrate, C. I. No. 2444, Pasha, C. I. No. 984, Pegan, C. I. No. 2454, Sulu, C. I. No. 1022, Watho, C. I. No. 2458, Welcome, C. I. No. 2439, Weider, C. I. No. 1021, and White Gatami, C. I. No. 920.

There apparently is no correlation between rust resistance and mildew resistance. Most of the rust-resistant varieties are susceptible to mildew and vice versa. In some cases the same variety may carry resistance to one or more of the physiologic forms of leaf rust and also to one or more of the physiologic forms of mildew. The varieties Bolivia, C. I. No. 1257, Sulu, C. I. No. 1022, and Weider, C. I. No. 1021, were outstanding for their marked resistance to all the physiologic forms of leaf rust and powdery mildew studied.

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THE BIOLOGY AND MORPHOLOGY OF THE BRACONID CHELONUS ANNULIPES WESM., A PARASITE OF THE EUROPEAN CORN BORER

BY

ARLO M. VANCE

Assistant Entomologist, Division of Cereal and Forage Insects, Bureau of Entomology

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INTRODUCTION

Among the 30 or more known parasites of the European corn borer (*Pyrausta nubilalis* Hübn.) in Europe are found six species of Braconidae. Only one of these braconids, *Microbracon brevicornis* Wesm., is a true external parasite, living gregariously on the host larva. Its biology and anatomy have been treated by Genieys (*3*),[2] who considered it under the genus Habrobracon. Two others, *Macro-*

[1] The present study of *C. annulipes* was begun in the summer of 1929 at the European parasite laboratory, Hyères, Var, France, and continued with various interruptions for a little over one year. The writer is very grateful for the constant interest of H. L. Parker, under whose guidance it has been a privilege to work, and for the helpful association of H. D. Smith, a fellow worker. He is indebted to C. Ferriere, of the British Museum, for his determination of the species, to Hugh Scott, of the same institution, for a translation of Thomson's Latin description, and to R. A. Cushman, of the taxonomic unit of the Bureau of Entomology, for the identification of all hyperparasites. He also expresses his appreciation to Esther Hart for her drawing of the adult, to B. E. Hodgson for his photograph of the cocoon, and to Theodore Malama for assistance in the rearing work.

[2] Italic numbers in parentheses refer to Literature Cited, p. 48.

centrus gifuensis Ashm. and *Apanteles thompsoni* Lyle, are also gregarious in habit, but live within the host. Parker (*6*) has published the results of his studies on the polyembryonic development, biology, and morphology of the former, and the writer (*14*) has published a bulletin on the latter. The braconids *Microgaster tibialis* Nees, *Chelonus annulipes* Wesm., and *Meteorus nigricollis* Thoms. occur as solitary internal parasites of the borer. The last-named species, however, is only occasionally found parasitic upon Pyrausta and is a negligible factor in the control of this host. Parker (*7*) has described its early stages and pointed out several interesting phases of its biology.

Chelonus annulipes, as a parasite of *Pyrausta nubilalis*, was first discovered by Parker in 1925, when three specimens were reared from cocoons collected in corn at Piacenza, Italy, in the south Padovian zone,[3] on July 29, and another cocoon was taken at Bergamo, in the north Padovian zone, on August 5. In 1926, 11 more specimens were reared from cocoons found near Bergamo. Thompson and Parker (*12*), who listed the parasite as *Chelonus* sp., stated that the species seemed to approach *C. carbonator* Marshall. It was their belief, based on the fact that the parasite cocoon normally bore the head capsule of the fourth-instar or fifth-instar host larva, that the eggs of this parasite were laid in some early stage of *P. nubilalis*, and they said in a footnote: "So far as is known all species of the group to which Chelonus belongs oviposit in the egg of the host."

No specimens of *Chelonus annulipes* were found during the collection of corn-borer parasites near Bergamo in 1927, and only a few cocoons were discovered in the same region in 1928. In the late summer of 1928 Parker made an extended search for this parasite in the "pump lands" of the Plavisian, Venetian, and south Padovian zones, and finally succeeded in locating a field of corn in the vicinity of St. Giorgio di Nogaro (Plavisian zone) in which parasitism by *C. annulipes* amounted to 9.9 per cent. In several other fields near by a lighter degree of parasitism by the same species was found, and a little later, at Piove di Sacco (Venetian zone), a few Chelonus cocoons were collected.

With such evidence in hand it was decided to inaugurate a drive for this parasite in the immediate region of St. Giorgio di Nogaro during the following summer. Accordingly the writer went there on July 20, 1929, and at once began field operations, which resulted in the collection and shipment in cold storage to the United States of 1,432 cocoons of *C. annulipes*.

A study of the biology of the parasite later brought out the fact that the species overwintered as a late first-stage larva within the body of the hibernating host larva, and that a more advantageous method of procuring the parasite in quantity was to collect large numbers of the dormant Pyrausta larvae and ship them direct to the United States, where the parasite would emerge in the spring. Such collections were made during the winter of 1929–30, and from these larvae 9,335 adults of *C. annulipes* were reared, bringing the total number of individuals shipped to 10,767.

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[3] For a discussion of the zones the reader is referred to the section on geographical distribution.

SYSTEMATIC POSITION AND IDENTIFICATION

Chelonus annulipes Wesm. is a braconid belonging to the subfamily Cheloninae.

According to both Dalla Torre (*1*) and Marshall (*5, p. 366–383*) the recognition of a genus known as Chelonus dates as far back as 1807, when the name was used by Jurine. Since that time various systematists have recorded and described many species of the genus. Nevertheless, the group has always been considered by students of taxonomy as difficult and extremely confused.

C. Ferriere, of the British Museum of Natural History, is responsible for the identification of this species from a study of several male and female specimens. His determination was based largely upon the description given by Thomson (*13, p. 572–573*). The species was previously listed as *C. inanitus* by Parker et al. (*8*).

PREVIOUS STUDY OF SPECIES OF CHELONUS

Notwithstanding the mention in systematic literature of a large number of species of the genus Chelonus, little biological or morphological work upon any of the group seems to have been undertaken. Various entomologists of different countries have at times listed certain species as parasitic upon particular insect pests and mentioned numerous points in their biology, but in most instances the references have been very brief.

In 1908 Silvestri (*10, p. 154–157*) made a short contribution on the two species *C. orientalis* Silv. and *C. elaeaphilus* Silv. as parasites of the olive moth, *Prays oleellus* Fab. In addition to descriptions of the adults, the eggs of the two species were described, and, in the case of *C. orientalis*, the external characters of the last-stage larva and the cocoon were given and the egg and last-stage larva illustrated. Brief notes upon the distribution, biology, and economic importance of these species were also included.

In 1912 the first detailed observations on the biology of any species of Chelonus were made by Pierce and Holloway (*9*) in their notes on *C. texanus* Cresson. These authors were the first to record oviposition by a member of the genus as taking place in the eggs of the host insect, and they discussed the occurrence, oviposition, and rearing of that species from both *Heliothis obsoleta* Fab. and *Laphygma frugiperda* S. and A.

Chelonus sonorensis Cam. has been mentioned by Van Zwaluwenburg (*15*) as the most important parasite of the moth borer *Chilo loftini* Dyar in western Mexico, where, in 1924, it parasitized about 23 per cent of the Chilo present in volunteer rice. Oviposition took place in the eggs of the host, and the parasite issued from the half-grown host larva to spin its cocoon. The life cycle from egg to adult under laboratory conditions was found to be 35 days.

Another species, *C. blackburni* Cameron, has been recorded by Willard (*17*) as a parasite of the pink bollworm, *Pectinophora gossypiella* Saund., in Hawaii, but few notes are given on its biology.

In his work on the fall army worm, *Laphygma frugiperda*, Luginbill (*4*) has listed *C. texanus* as one of the most important parasites of that insect, and has discussed, in several pages, its bi-

ology and seasonal history. He has also included good drawings of the adult, last-stage larva, pupa, and cocoon of that species.

Vickery (*16*) has also considered the importance of *C. texanus* as a parasite of the fall army worm and has treated several interesting points in its biology.

GEOGRAPHICAL DISTRIBUTION

C. annulipes, occurring as a parasite of *P. nubilalis*, has so far been found only in the northern part of Italy. The region of its known distribution (fig. 1) has, for the purpose of convenience, been divided into certain zones, the separation being based upon the geological divisions used by Thompson and Parker (*12*), and by Parker, Vance, Smith, and Gamkrelidze (*8*).

The geographical positions of the zones mentioned in this paper are briefly as follows:

The north Padovian zone, including the region of Bergamo, covers the plains of Lombardy and consists of that area in the northwestern part of Italy which is bounded on the west and north by the Alps and on the south by the Ligurian Appennines. On the east its border extends from the junction of the Trebba and Po Rivers along the Po itself as far as the wide bend of the Adige River. Practically all this region is drained by the Po River and its tributaries.

The south Padovian zone, containing the region of Piacenza, in Emilia, may be considered as a triangular area lying south of a line drawn from the base of the Ligurian Alps along the Trebba, the Po, and the easterly directed part of the Adige Rivers, bordered on the south by the Toscan Apennines, and spreading east to the shores of the Adriatic Sea.

The Venetian zone, consisting largely of the low country in the Venice and Padova regions, has a boundary which follows the Adige River from its mouth to the point where it reaches the foothills of the Trentin Alps and continues in a northeasterly direction along the base of the mountains to the Piave River, which it parallels to the Adriatic Sea, just north of the gulf of Venice.

The Plavisian zone, in the extreme northeastern corner of Italy, a region sometimes known as the Plains of Friuli, is a somewhat elliptical area whose northern half is hemmed in by the Alps and whose southern boundary follows the Piave River from the mountains to the sea and then goes along the coast toward Trieste. The city of Udine is situated in the north central part of this zone.

Throughout most of the plains of northern Italy, corn, wheat, oats, and field legumes are common crops, and garden vegetables, muskmelons, and watermelons, as well as various fruits and vines, are grown more or less generally. There exists, however, a certain diversity in the agriculture of the different zones just defined. In the north Padovian zone considerable rice is grown, and walnuts and hazelnuts are cultivated. The land in the south Padovian zone is devoted to a mixed type of agriculture. Quantities of tomatoes are grown around Piacenza and muskmelons and watermelons in the lowlands near Ferrara. Considerable hemp, tobacco, and sugar beets are grown from Ferrara south toward Bologna. Tobacco and sugar beets are also grown in the Venetian zone, but in the Plavisian

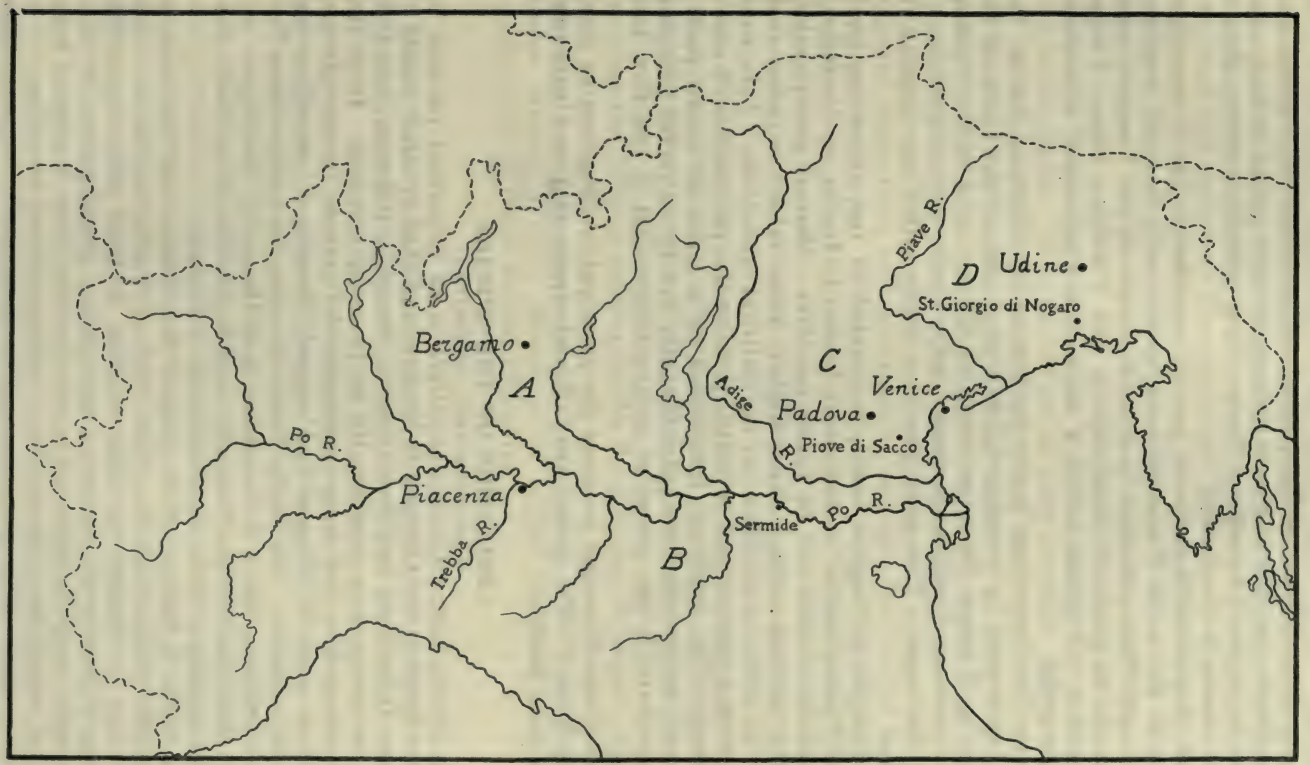


FIGURE 1.—Map of northern Italy showing zones where *Chelonus annulipes* has been found as a parasite of *Pyrausta nubilalis:* A, North Padovian; B, south Padovian; C, Venetian; D, Plavisian. Specimens of the parasite have been collected at all points on the map except at Padova and Venice

zone they are less extensively cultivated, and corn and cereals are prominent.

Chelonus annulipes has been taken in all of the four zones, and it is supposed that the species is present, to some extent at least, over this entire region of northern Italy. It is certain, however, that it is very unevenly distributed.

From present information it may be considered that *C. annulipes* is rare in the north Padovian zone, occurs only in small numbers in the south Padovian zone, is more numerous in the Venetian zone, and exists in greatest abundance in the Plavisian zone. Future studies may, of course, reveal a wider distribution and occurrence in other zones.

In the Plavisian zone heavy parasitism by Chelonus has so far been found only in a rather limited area around the town of St. Giorgio di Nogaro (18 miles south of Udine), and in the "pump lands" covering a radius of about 5 miles south, toward the lagoons along the coast. This area lies in a basin called the Laguna di Marano.

St. Giorgio di Nogaro, itself, is situated 23 feet above sea level, but the "pump lands" to the south, known in Italian as "bonifica," are reclaimed lands and lie below sea level. Normal precipitation, plus the natural seepage from higher water tables, supplies such land with sufficient moisture for agricultural operations. This, combined with a natural soil fertility, permits the production of excellent crops. The fields are intersected by a series of canals partly filled with water which is kept sufficiently low by powerful pumping stations that lift the excess to such a height that it can flow into the sea.

Corn of the flint type is one of the principal crops grown on these "pump lands." The plants are tall and strong and as a rule produce a good yield.

LIMITATION OF THE SPECIES

It is known that *Chelonus annulipes* is an important parasite of the corn borer at St. Giorgio di Nogaro, and that in other points of northern Italy, such as Piove di Sacco, Sermide, Piacenza, and Bergamo, it occurs only occasionally or in small numbers. It is also a determined fact that from thousands of Pyrausta larvae collected in various parts of France and central Europe, *C. annulipes* has never been reared. Yet Dalla Torre (*1*) cites the species from Belgium, Germany, Italy, Switzerland, and Hungary; Szépligeti (*11, p. 234*) describes it from Hungary; and De Gaulle (*2, p. 73–88*) lists it in his catalogue of the Hymenoptera of France.

This much is known of its general distribution and its more or less specific confinement to certain regions, but to ascribe any definite values to climatic or other factors, in their effect upon this parasite, without more extensive and precise investigations of both the parasite and its host and more data on their biological relationships, would be a speculative, if not hazardous, procedure.

From a study of temperature and precipitation in regions where Chelonus occurs in varied numbers, it has been learned, in one instance, that at St. Giorgio di Nogaro (Udine), where the species has

so far been found most plentiful, the monthly temperatures vary little from those prevailing at Bergamo, where the parasite is extremely rare, the former locality having a mean annual temperature of 55.4° F. and the latter, of 54.1°. The annual rainfall in the two places is practically the same—47 inches at St. Giorgio di Nogaro and 46.6 inches at Bergamo—but there is a certain variation in its monthly distribution. During the period January to March, inclusive, St. Giorgio di Nogaro receives a little more rain than does Bergamo; while from May to November, inclusive, only a slight variation occurs. For April, however, the rainfall at St. Giorgio di Nogaro is 2 inches less and in December 2 inches more than at Bergamo. Whether either of these monthly differences has any effect upon the survival of Chelonus is not known. It might be conjectured that the resumption of development of the partly grown first-stage larva—which probably takes place about April, after overwintering within its fourth-instar host—together with the general weakness of the host at the time, produces a susceptibility to a climatic fluctuation, such as excessive rainfall, that might make itself apparent in an eventual limitation of the abundance of the species. A further study of this question, considered in relation to the physiological effect of the parasite on its host, would be very interesting, and is certainly necessary before any conclusions can be drawn.

Humidity may be a contributory, and perhaps extremely important, factor in the successful existence of Chelonus, although the results of rearing experiments in the laboratory do not lend strength to the view. It is probably true, however, that the atmosphere covering the favored habitat of the St. Giorgio di Nogaro region—the "pump lands" lying near the sea and below its level, and interspersed with canals—is more humid than would be found in places situated farther inland or at higher altitudes, where the species exists in much smaller numbers.

ECONOMIC IMPORTANCE

The economic importance of *C. annulipes* as a parasite of the European corn borer in Italy is best illustrated by the figures given in Table 1. It is readily seen that the percentage of parasitism in all regions studied has been considerably higher in the first than in the second generation of host larvae. In 1929, at St. Giorgio di Nogaro, for instance, the average parasitism in the first generation was 16.9 per cent, while in the second generation it was only 3.5 per cent.

In the region of Bergamo, in the north Padovian zone, where nearly a million specimens of *P. nubilalis* and its parasites have come under observation during the 5-year period, 1925 to 1929, inclusive, *C. annulipes* has been practically negligible. It is also scarce in the vicinity of Sermide in the south Padovian zone.

On the other hand, in the environs of St. Giorgio di Nogaro, in the Plavisian zone, Chelonus must be considered one of the factors in the control of the corn borer. At Piove di Sacco, in the Venetian zone, it is also of economic importance. In Table 2 are given the results of a survey of parasitism in this latter region made during August, 1929, by an assistant. A total of 28 cornfields were visited,

and an average parasitism by Chelonus of 8 per cent was found for the region. In three fields the parasitism exceeded 20 per cent, and a maximum of 28.2 per cent was discovered in one field.

TABLE 1.—*Parasitism of larvae of Pyrausta nubilalis by Chelonus annulipes in northern Italy, 1925–1929*

Year	Locality	Zone	First generation			Second generation		
			Host specimens	Average parasitism	Maximum parasitism in single field	Host specimens	Average parasitism	Maximum parasitism in single lot [1]
			Number	*Per cent*	*Per cent*	*Number*	*Per cent*	*Per cent*
1925	Piacenza	South Padovian	[2] 3					
	Bergamo	North Padovian	[2] 1					
1926	do	do	192,703	−0.01				
1927	do	do	172,261	0				
1928	do	do	312,153	.01				
	St. Giorgio di Nogaro	Plavisian	375	3.20	9.9	1,045	0.5	1.4
	Piove di Sacco	Venetian				808	.1	.6
1929	Bergamo	North Padovian	225,267	.02				
	Sermide	South Padovian	162	.60	.6	1,688	.1	
	St. Giorgio di Nogaro	Plavisian	12,127	16.90	28.6	2,652	3.5	8.5
	Piove di Sacco	Venetian	1,441	8.00	28.2	973	.1	

[1] Each lot contained from 250 to 300 larvae. [2] First record.

TABLE 2.—*Field parasitism of larvae of Pyrausta nubilalis by first-generation Chelonus annulipes in the region of Piove di Sacco, Italy, 1929*

Field No.	Date	Locality	Parasitism	Field No.	Date	Locality	Parasitism
			Per cent				*Per cent*
1	Aug. 1	Brugine	8.3	11	Aug. 5	Piove di Sacco	17.5
2	Aug. 2	do	8.3	12	Aug. 6	Arzarello	12.8
3	do	Campolongo Maggiore	10.0	13	Aug. 7	Arzer Grande	7.1
4	do	do	15.3	14	do	do	8.3
5	Aug. 3	Piove di Sacco	10.7	15	do	do	10.7
6	do	do	4.5	16	Aug. 8	Campagnola	28.2
7	Aug. 5	do	2.9	17	do	do	25.0
8	do	do	8.3	18	do	do	26.5
9	do	do	7.7	19	Aug. 9	Correzzola [1]	2.2
10	do	do	4.5				

[1] In 9 other fields of this locality no parasitism by *C. annulipes* was found.

In 1929 parasitism by Chelonus in the first generation of the corn borer was not evenly distributed in the different cornfields examined in the vicinity of St. Giorgio di Nogaro. In certain fields the parasitism was very low while in others it exceeded 20 per cent. In five of the fields where Chelonus cocoons were most numerous the parasitism was as follows: 10, 18.8, 21.5, 21.8, and 28.6 per cent, with an average of 21.6 per cent. The maximum parasitism in any single field was 28.6 per cent.

Both the heaviest infestation by the corn borer and the highest parasitism of first-generation borers by *C. annulipes* were found in fields of early maturing corn which had reached the silking stage by the latter part of July. In the younger corn there appeared few hosts or parasites. Later, however, the slower maturing corn received the bulk of infestation by the second-generation borers which were attacked by the second brood of Chelonus.

In the above area the average infestation by the corn borer in six different fields examined equaled 22.7 per cent of the plants, with a maximum of 40 per cent in one field.

While the parasitism of the second generation, or overwintering host larvae, is numerically less than that found in the first generation, it is still a factor of importance. In Table 3 has been listed the degree of parasitism by *C. annulipes* in nine different lots of hibernating corn-borer larvae from which parasites were bred in the spring of 1930. A total of 2,652 borers were handled, and an average parasitism of 3.5 per cent was determined. The maximum for any single lot was 8.5 per cent.

TABLE 3.—*Parasitism of larvae of Pyrausta nubilalis*[1] *by Chelonus annulipes of the second generation at St. Giorgio di Nogaro, Italy, 1929*

Lot No.	Host specimens	Chelonus annulipes	Parasitism	Lot No.	Host specimens	Chelonus annulipes	Parasitism
	Number	*Number*	*Per cent*		*Number*	*Number*	*Per cent*
1	319	1	0.3	7	268	15	5.6
2	274	2	.7	8	280	16	5.7
3	291	5	1.7	9	306	26	8.5
4	283	5	1.8				
5	319	8	2.5	Total	2,652	93	3.5
6	312	15	4.8				

[1] The host larvae from which the above data were obtained were collected in the field during the winter months of 1929–30 and the parasites reared from them under controlled conditions in the laboratory.

HOST RELATIONS

The writer has bred *Chelonus annulipes* from *Pyrausta nubilalis* only. A few of the large round eggs of *Sesamia* sp. were several times placed before a female of Chelonus, but she refused to oviposit in them. Possibly this species of parasite would attack certain other Lepidoptera whose eggs are laid in masses similar to those of Pyrausta.

Pierce and Holloway (*9*), in their observations on *Chelonus texanus*, found that species to parasitize the solitary eggs of *Heliothis obsoleta* as well as those of *Laphygma frugiperda* deposited in large masses, and they have called attention to this host relationship. Vickery (*16*) has since added *Laphygma exigua* Hbn. and *Prodenia* sp. as hosts of *C. texanus*.

Only the olive moth, *Prays oleellus* Fab., was mentioned by Silvestri (*10, p. 154–157*) as host of *Chelonus orientalis* and *C. elaeaphilus*. Willard (*17*), in speaking of the parasitism of the pink bollworm (*Pectinophora gossypiella* Saund.) by *C. blackburni*, refers to the probability that the high percentage of parasitism by that species during a certain month was due to early development upon another host which permitted large numbers of the parasite to be in the field at an opportune time to attack the pink bollworm.

DESCRIPTION

ADULT

The adult (fig. 2) of *Chelonus annulipes* differs considerably in appearance from the other hymenopterous parasites of the European corn borer. It is a black, robust insect with smoky-colored wings and an abdomen covered by a single hard, dorsally convex sclerite, and little resembles the more wasplike forms of some of the braconids.

The following is a translation of the original description given to the species by Thomson (*13, p. 572–573*) and used by Doctor Ferriere in his determination:

C. annulipes: Black, with genae swollen and strigose, the frons subopaque and striate punctate, front tibiae and knees pale, hind tibiae broadly pale at the middle, postscutellum with a toothed and elevated carina, scutellum with its disk flat and almost smooth. Length, 6–7 mm.

* * * Best distinguished by its black tegulae, swollen genae, almost opaque and substriate punctate frons, by the apex of the abdomen not being shining and compressed, more rarely bimaculate, by the scutellum with disk flat and almost smooth, and by the female having the antennae about 24-jointed and shorter; very easily distinguishable from *C. rugigena* and *C. humilis* by the female having the antenna dilated and flattened above the middle, by the dentate-elevated carina on the postscutellum, and by the smaller body.

FIGURE 2.—*Chelonus annulipes*, adult female. × 8

EGG

Length at oviposition, 0.2 mm.; greatest width, 0.04 mm.

The egg (fig. 3, A) of *C. annulipes*, immediately after deposition in a Pyrausta egg, is cylindrical, arcuate, of nearly equal diameter for its entire length, but slightly narrower at the caudal extremity. Both its cephalic and caudal ends are well rounded. It is translucent white in color and has a smooth glistening surface. As development proceeds the egg (fig. 3, B) becomes distended, and the cephalic end broadened.

FIRST-STAGE LARVA

MEASUREMENTS

At hatching: Length of larva, 0.2 mm.; width of head, 0.075 mm.; width of first thoracic segment, 0.047 mm.; width of first abdominal segment, 0.032 mm.; length of mandible, 0.038 mm.

At age of 10 days: Length of larva, 0.72 mm.; width of first thoracic segment, 0.197 mm.; width of first abdominal segment, 0.144 mm.; width of head and length of mandible same as on hatching.

EXTERNAL ANATOMY

The newly hatched larva (fig. 4, A) of *C. annulipes*, found still partly surrounded by clinging masses of the serosal cells, has a translucent white body of eight more or less distinct segments. The head (*h*), in proportion to the other segments, is very large. It is rather square, slightly narrower at the posterior than at the anterior portion, except at the extreme front where the labrum and its processes form a slight projection. Though but slightly more than half as wide as the head, the first thoracic segment is only a little broader than the segments which follow. The anal segment, longer in itself than the other abdominal segments combined and in reality the fusion of several divisions, is further lengthened into a blunt appendage (*aap*) which is inclined ventrally.

A varying number of short translucent spines, pointing in a posterior direction, are arranged in two or three irregular rows across the dorsal surface of the second and third thoracic and the first four abdominal segments. On the last abdominal segment the spines are placed farther toward the front.

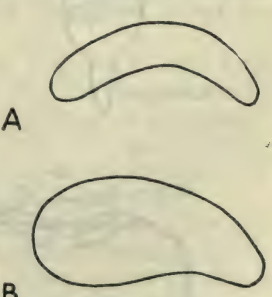


FIGURE 3.—Egg of *Chelonus annulipes*: A, Immediately after deposition in host egg; B, 2 days old and ready to hatch

The differentiation of the larval segments seems to be a gradual process, and accordingly the later first-stage larva (fig. 4, B) varies from the newly hatched larva just described. The larva, when 10 days old, has changed considerably in its external appearance. The head (*h*) has remained the same size, while the body segments have enlarged. A peculiar aspect of this late first-stage larva is the relatively large segment back of the head which is at least three times as long as either of the following two segments. However, the writer has never been able to observe any further division of this segment and has taken it to represent the usual first thoracic segment.

In addition to the head, now relatively small in proportion to the body segments, there are three thoracic and six abdominal segments. The last of these segments is approximately four times as long as any of the other abdominal segments and bears on its dorsal surface a round raised area which represents an early phase in the evagination of the anal vesicle (*av*). The dorsal spines on the second and third thoracic and the six abdominal segments, in contrast to the increased size of the larva, are almost inconspicuous.

The mouth parts (fig. 4, C) at the front of the head are situated somewhat ventrally. Viewed from beneath, the labium (*lb*) appears to curve inward from the region near the base of the mandibles (*md*) and at the middle to form a rather square lip which covers a chitinous structure of similar shape lying within the mouth opening and behind which the points of the two mandibles approach. Near the

middle of the lower lip, where it starts to form its squared portion, are located two labial setae.

The anteriorly rounded labrum (*lbr*) is pushed out beyond the curve of the mandibles, and possesses at its outer edge two widely separated processes (*lbrp*), which may be thrust forward from, or drawn in toward, the mouth opening. Each process divides at the

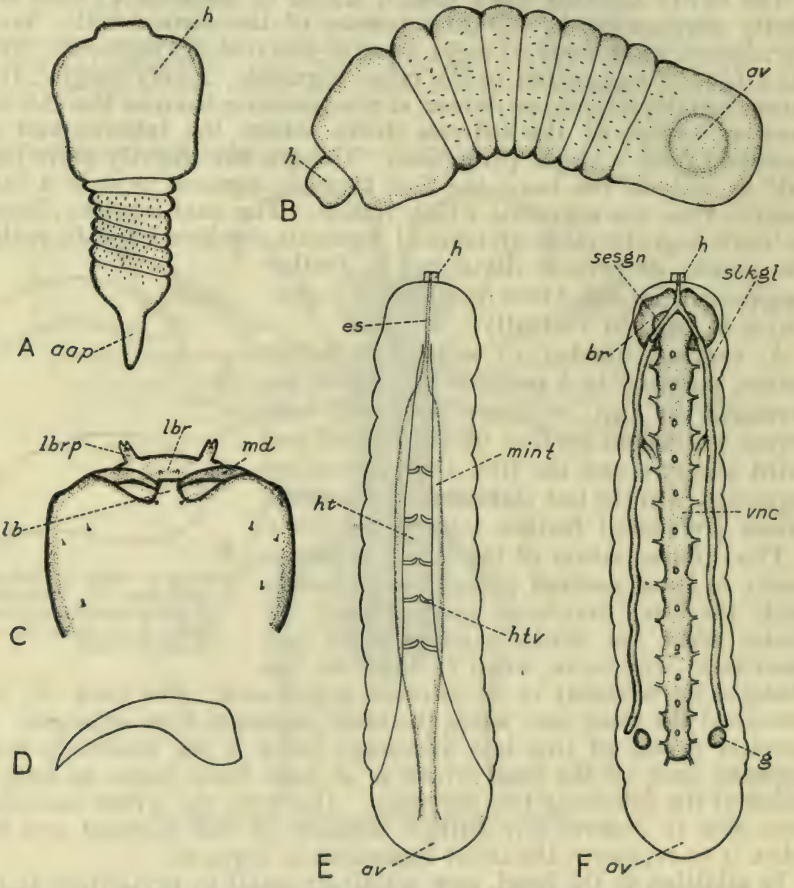


FIGURE 4.—*Chelonus annulipes*, first-stage larva: A, Dorsal view of newly hatched larva; B, dorsal view of larva 10 days old; C, ventral view of head; D, mandible; E, internal anatomy of larva viewed dorsally; F, internal anatomy of larva viewed ventrally. *aap*, Anal appendage; *av*, anal vesicle; *br*, brain; *es*, esophagus; *g*, gonad; *h*, head; *ht*, heart; *htv*, heart valve; *lb*, labium; *lbr*, labrum; *lbrp*, labrial process; *md*, mandible; *mint*, mid-intestine; *sesgn*, subesophageal ganglion; *slkgl*, silk gland; *vnc*, ventral nerve cord

extremity into three short blunt points. Near the lower edge of the upper lip appear two (and sometimes three) minute peglike structures which are probably sensorial in nature.

The mandibles (fig. 4, D) are dark brown in color, smooth, sharply pointed, decidedly curved on their inner edge, and well chitinized, especially toward their tips. Three small regularly arranged and widely separated spines occur ventrally, on each half of the head proper.

INTERNAL ANATOMY

The degree of development of the various organs differs with the age of the larva. The following description applies to a larva about 10 days old:

The digestive tract consists of a slender esophagus (fig. 4, E, *es*) leading from the mouth to the enlarged mid-intestine (*mint*) in the posterior region of the first thoracic segment. The tube forming the mid-intestine is not greatly distended and narrows slightly in the last four abdominal segments toward its culmination on the interior dorsal wall of the anal vesicle (*av*), which is considered the evaginated hind-intestine.

The heart (*ht*), leading from the anal vesicle, gradually narrows toward the anterior extremity of the first thoracic segment. Five valves (*htv*), located in the first five abdominal segments, control the forward flow of blood, which enters from the posterior opening and probably also from tiny ostia situated laterally along the heart in close proximity to the valves.

The nervous system is composed of a brain (fig. 4, F, *br*) and subesophageal ganglion (*sesgn*) filling most of the first thoracic segment, and a nerve cord (*vnc*) of 12 thick ganglia, each separated from the others by two closely placed heavy cords. In each of the occupied segments two lateral cords are given off from each of the main ganglia and nerves branch posteriorly from the last two.

In the forward part of the first thoracic segment the two lateral silk glands (*slkgl*) branch from the short common duct leading from the base of the mouth and extend posteriorly. Each gland becomes bifurcated in the third thoracic segment, and the two branches continue to the vicinity of the seventh abdominal segment. The gonads (*g*) appear as round or somewhat pear-shaped bodies lying in the region of the seventh and eighth abdominal segments.

SECOND-STAGE LARVA

MEASUREMENTS AND EXTERNAL ANATOMY

Length near end of stage, 3 mm.; width, 0.5 mm.

The larva (fig. 5) of this stage is characterized by a rather straight and uniformly roundish body destitute of spines, a thick-walled and bluntly pointed anal vesicle (*av*) which is often indented dorsally, and a round-shaped head (*h*) possessing a very thinly chitinized armature. The body is creamy in color and consists of the head, three thoracic, and nine abdominal segments, not counting the anal vesicle. On the ventrum of each of the three thoracic segments occurs a pair of leg buds, and laterally on the second and third thoracic segments are two pairs of rudimentary wings. The histoblasts of the external genital appendages are located on the ventral surface of the eighth and ninth abdominal segments in the female, and on the ninth in the male larva.

The mouth parts appear as several raised areas on the forward part of the head and are very lightly chitinized. No strong mandibles are present, as in the first and last stages. On the labrum, however, appear to be located two pairs of small sensorial structures, and the round markings of the antennal rudiments are visible on the upper part of the head.

Usually the head cast and old skin of the first-stage larval molt are to be found on one of the last abdominal segments of the second-stage larva.

INTERNAL ANATOMY

The internal anatomy of this larva differs little essentially from that of the first-stage larva. All organs have increased in size, and the two silk glands, bifurcating in the third thoracic segment and lying very close to the body wall, have become more convoluted. The appearance of the gonads and heart is little different from that in the first-stage larva.

A large part of the head is occupied by the brain, and the nerve ganglia are located along the ventral floor of the body cavity. The tracheal system, although still closed, seems to be filled with air and has 10 principal branches in addition to the cephalic and caudal extremities. The two longitudinal trunks are united by a short dorsal transverse commissure in the first thoracic segment.

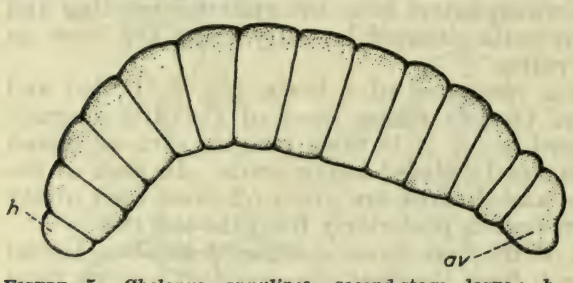


FIGURE 5.—*Chelonus annulipes*, second-stage larva: *h*, Head; *av*, anal vesicle

Urate cells are closely associated with the lateral fat lobes of the second to seventh abdominal segments; in the seventh there are only a few of these excretory cells. Fat cells seem to be present in all segments of the body except the head and the last abdominal segment.

LAST-STAGE LARVA

MEASUREMENTS

After external feeding: Length, 7.5 mm.; width, 2 mm.; length of mandible, 0.214 mm.; diameter of third thoracic spiracle, 0.034 mm.; average length of large dorsal spines, 0.081 mm.

EXTERNAL ANATOMY

The last-stage larva (fig. 6, A), upon issuance from the host, is cylindrical, widening gently in diameter from the head (*h*) toward the abdominal segments and then becoming somewhat smaller at the rounded caudal extremity, where the anus (*a*) is located. The body is creamy or yellowish in color, and has a glistening appearance. Microscopical examination shows the skin to be thickly covered with tiny blunt spines. Fourteen segments are present. The last two abdominal are somewhat transparent and contain only the ramifications of the tracheae, a few scattered fat cells, and the hind intestine with the anus.

A number of tiny translucent spines are distributed, dorsally and laterally, over the various thoracic and abdominal segments (with the exception of the anal segment), and dorsally on each

of the abdominal segments two to six, inclusive, are located a few long and brown chitinized spines. On each of these five segments the large chitinized spines occur in two short transverse rows, one on each side of the dorsal heart line but slightly laterad.

The exact number of such spines in any group or on any segment is not constant for the same or for different larvae. The following example of their abundance and distribution is typical:

Second abdominal segment, 4 on left and 3 on right side of heart line, or a total of 7.

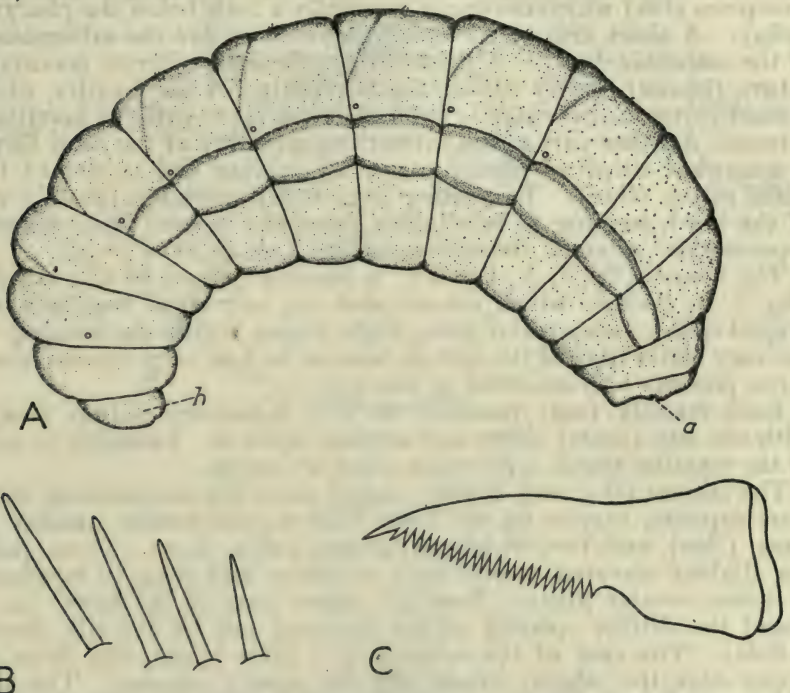


FIGURE 6.—*Chelonus annulipes*, last-stage larva: A, Lateral view; B, set of dorsal spines; C, mandible. *a*, Anus; *h*, head

Third abdominal segment, 4 on left and 5 on right side of heart line, or a total of 9.

Fourth abdominal segment, 3 on left and 4 on right side of heart line, or a total of 7.

Fifth abdominal segment, 3 on left and 2 on right side of heart line, or a total of 5.

Sixth abdominal segment, 1 on left and 1 on right side of heart line, or a total of 2.

Total of 15 spines on each side of heart, or 30 in all.

These spines (fig. 6, B) are not all of the same size, and usually there is a gradation downward in their length from the median line laterad.

From the well-developed tracheal system spiracles open near the anterior margin (laterad and slightly dorsad) of the second thoracic and first six abdominal segments. In the third thoracic segment the tracheal termination is only a mitten-shaped stub, located internally.

The arrangement of the integumentary muscles is responsible for decided lateral lobes on the first eight abdominal segments.

The chitinized head capsule or epicranium covers the superior and lateral portions of the head. This part is set off from the softer buccal region by the epicranial suture (fig. 7, A, *epsu*) which is arched over the mouth and labrum, curves slightly downward on each side, and is continued laterad, coincident with the superior maxillary suture (fig. 7, B, *smxsu*) under the upper fold of the maxilla, and then along the side of the head to connect with the tentorial crosspiece (*ten*) which continues internally a little below the pharynx (*phy*). A short arm of the epicranium serves for the articulation of the mandible (*md*). A thickening, called the inferior maxillary suture (*imxsu*), partly defines the lower edge of the maxilla, while a short chitinous bar extends from the superior to inferior maxillary sutures. Another part of the supporting structure of the head forms a somewhat elliptical border about the labium and is termed the labial suture (*lbsu*). Two rather large round markings near the top of the head, seeming to be slightly depressed toward their centers, represent the antennal rudiments. (Fig. 7, A, B, *ant.*)

The mouth (fig. 7, A, B, *mth*) is bordered above by the labrum (fig. 7, A, *lbr*) on which are situated six very short regularly arranged spinous sensorial organs, while deeper within the opening on the very under edge of the labrum seem to be four very minute structures, possibly also sensorial in function.

Each maxilla (*mx*) possesses an oval 2-knobbed palpus (*mxp*) with one seta (*mxse*) above and another below it. Laterally to each of the maxillae stands a group of about six spines.

The labium (*lb*), very slightly raised above the surrounding chitinous support, carries on its lower half a considerable number of setae (*lbse*) and two widely separated palpi (*lbp*). These palpi are slightly elevated, rather oval in shape, and seem to terminate in three circular knobs. Near the upper part of the lower lip is found the slitlike opening of the common duct of the silk glands (*slkdo*). The area of the opening is a little raised, and from its upper edge the labium slopes into the mouth opening. The surface of the cuticle in this region is divided into many small polygonal areas. Below the labium a considerable number of spines are irregularly arranged.

From under the maxillae the points of the two mandibles (*md*) appear in the mouth opening. Each mandible (figs. 6, C; 7, A; 7, B) has a broad rounded base which articulates in the curved apophyses of the arms which extend laterad along the ventral margin of the epicranium, and tapers to a sharp distal point. It is hollow (at least in its basal portion), well chitinized, brown in color, and possesses along its inner edge a row of about 25 long sawlike teeth.

The appearance of the larva at this stage, after it has finished external feeding, is more plump, the lateral lobes are more swollen, and there is also a difference in coloration due to the contents of the peritropic membrane, which now varies from a light to a dark brown. With the external feeding the larger urate cells become more apparent. They are found only in the second to eighth abdominal segments, where they occur laterally in close association

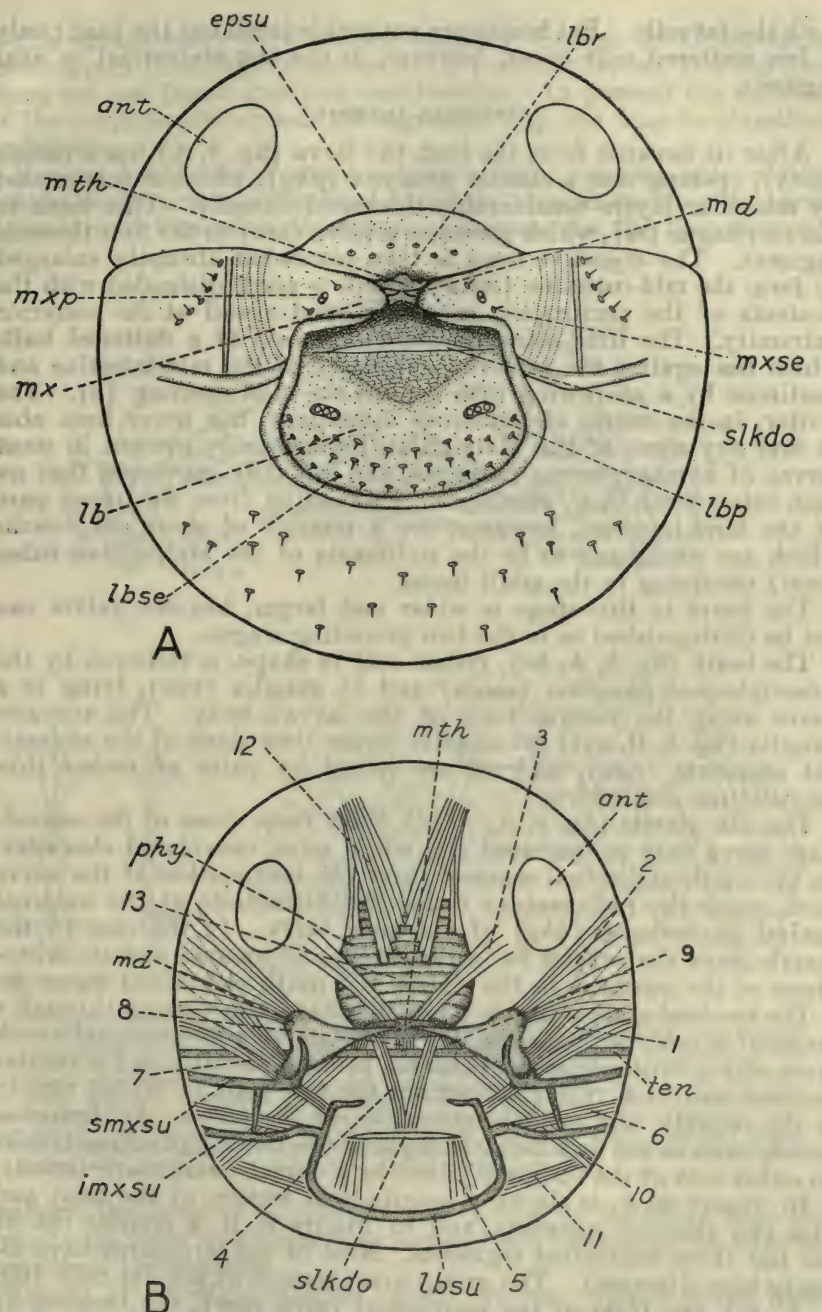


FIGURE 7.—*Chelonus annulipes*, last-stage larva; A, Front view of head; B, front view of head musculature. *ant*, Antennal rudiment; *epsu*, epicranial suture; *imxsu*, inferior maxillary suture; *lb*, labium; *lbp*, labial palpus; *lbr*, labrum, *lbse*, labial seta; *lbsu*, labial suture; *md*, mandible; *mth*, mouth; *mx*, maxilla; *mxp*, maxillary palpus; *mxse*, maxillary seta; *phy*, pharynx; *slkdo*, external opening of common duct of silk glands; *smxsu*, superior maxillary suture; *ten*, tentorial crosspiece; *1–13*, various sets of muscles described in the text

with the fat cells. Fat bodies are noticeable in all but the head; only a few scattered cells occur, however, in the last abdominal or anal segment.

INTERNAL ANATOMY

After its issuance from the host, the larva (fig. 8, A) has a mouth (*mth*), opening into a slender pharynx (*phy*), which is surrounded by muscular layers considerably thickened dorsally. This leads to the esophagus (*es*), which possesses a valve (*esv*) in the first thoracic segment. The digestive tract is then somewhat abruptly enlarged to form the mid-intestine (*mint*), which is much distended with the contents of the peritrophic membrane and closed at its posterior extremity. The hind-intestine (*hint*) consists of a flattened bulb, which lies against the posterior extremity of the mid-intestine and continues by a narrowing tube toward the anal opening (*a*). The writer, in the course of numerous dissections, has never been able to find any signs of the Malpighian tubes usually present in most larvae of hymenopterous parasites, and is firmly convinced that no such tubes occur in *C. annulipes*. Proceeding from the upper part of the hind-intestine, however, are a number of short outgrowths which are considered to be the rudiments of the Malpighian tubes (*mal*) occurring in the adult insect.

The heart in this stage is wider and larger, but the valves can not be distinguished as in the two preceding stages.

The brain (fig. 8, A, *br*), rather oval in shape, is followed by the subesophageal ganglion (*sesgn*) and 11 ganglia (*vnc*), lying in a chain along the ventral floor of the larva's body. The thoracic ganglia (fig. 8, B, *ngt*) are slightly larger than those of the abdominal segments (*nga*), and all are joined by pairs of rather thin longitudinal connectives.

The silk glands (fig. 8, A, *slkgl*) differ from those of the second-stage larva only in increased size and a more convoluted character. In the ninth abdominal segment, near the termination of the nerve cord, occur the rudimentary testes and histoblasts of the external genital appendages (*hbg*) of the male larva. In the case of the female larva the ovaries lie in the seventh abdominal and the histoblasts of the genitalia in the eighth and ninth abdominal segments.

The tracheal system (fig. 8, C) of this stage, functioning through a series of seven open spiracles (*sp*), consists of a longitudinal trunk from which 11 short lateral branches proceed dorsally and a similar number lead in a ventral direction, the two ends of which ramify in the cephalic and caudal extremities of the larva. All branches ramify, and in the first thoracic segment the two longitudinal trunks on either side of the body are joined by a dorsal commissure (*acom*).

In Figure 9, A, is shown a longitudinal section of the head and first two thoracic segments, and in Figure 9, B, a similar cut of the last three abdominal segments. Most of the structures have already been discussed. The group arrangement of the fat cells (fig. 9, A, *fc*), the form of the esophageal valve (*esv*), the location of the cells (*scpm*) which probably secrete the peritrophic membrane, and the attachment of the dorsal pharyngeal muscles (*phyml*), are illustrated. Figure 9, C, shows enlarged urate (*uc*) and fat (*fc*) cells and two oenocytes (*oen*), all from a last-stage larva.

The arrangement of the integumentary muscles of Chelonus is less complex than that of certain other parasitic larvae, and the fine fibers are not found grouped into bundles. In general the muscles of the thoracic and abdominal segments (fig. 10) may be classified as follows:

Ventral longitudinal muscles (*vlml*) occur on each side of the ventral nerve cord as a flat band of fibrous strands crossing the three thoracic and first nine abdominal segments. In the first thoracic

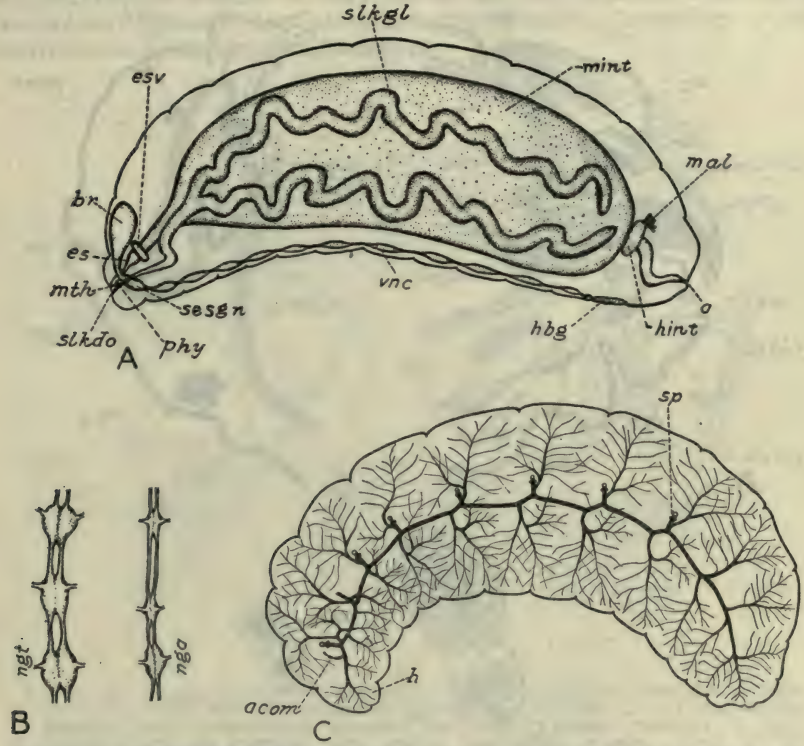


FIGURE 8.—*Chelonus annulipes*, last-stage larva: A, Internal anatomy viewed laterally; B, nerve ganglia of three thoracic and sixth, seventh, and eighth abdominal segments; C, lateral view of tracheal system. *a*, Anus; *acom*, anterior commissure; *br*, brain; *es*, esophagus; *esv*, esophageal valve; h, head; *hbg*, histoblasts of external genital appendages of male; *hint*, hind-intestine; *mal*, supposed rudiments of Malpighian tubes of adult; *mint*, mid-intestine; *mth*, mouth; *nga*, nerve ganglia of sixth, seventh, and eighth abdominal segments; *ngt*, nerve ganglia of three thoracic segments; *phy*, pharynx; *sesgn*, subesophageal ganglion; *slkdo*, external opening of common duct of silk glands; *slkgl*, silk gland; *sp*, spiracle; *vnc*, ventral nerve cord

segment the band is subdivided, and a few of its fibers near the upper edge form a set extending forward and mediad to the anterior margin of the segment.

Dorsal longitudinal muscles (*dlml*) are also present in the three thoracic and first nine abdominal segments and form a band, about equal in width to that of the ventral longitudinal muscles, along the upper part of each lateral half of the body. The fibers in the first thoracic segment occur in two groups. The upper group crosses the entire segment, and the lower, of about the same width, is

attached about two-thirds of the way toward the front of the segment.

Ventral oblique muscles (*voml*) occur in narrow bands, one of which is attached at a point near the lower anterior edge of the ventral longitudinal muscles in the first thoracic segment and crosses diagonally mediad to the upper posterior corner of that set in the same segment. This type of muscle is found similarly located in the second and third thoracic and the first abdominal segments.

FIGURE 9.—*Chelonus annulipes*, last-stage larva: A, Longitudinal section of head and first two thoracic segments; B, longitudinal section of eighth, ninth, and tenth abdominal segments; C, cells. *a*, Anus; *ao*, aorta; *bc*, blood cells; *br*, brain; *ctl*, cuticle; *es*, esophagus; *esv*, esophageal valve; *fc*, fat cells; *gn*, ganglion; *hbg*, histoblasts of external opening of genital appendages of male; *hint*, hind-intestine; *hyp*, hypodermis; *mal*, Malpighian tubes of adult; *mint*, mid-intestine; *ml*, muscles; *mth*, mouth; *oen*, oenocytes; *phy*, pharynx; *phyml*, pharyngeal muscles; *scpm*, secreting cells of peritrophic membrane; *slkdo*, external opening of common duct of silk glands; *ten*, tentorial crosspiece; *trcom*, tracheal commissure; *uc*, urate cell

Lateral oblique muscles (*loml*) are bands of about the same width as those of the ventral oblique muscles and occur in the second and third thoracic and first five abdominal segments. Each set is attached to the body wall at a point adjacent to the upper anterior edge of the ventral longitudinal band and runs dorsad and caudad to the lower posterior corner of the dorsal longitudinal muscles in each occupied segment. In the second and third thoracic and first abdominal segments these muscles appear as continuations of the ventral oblique sets.

Dorsoventral muscles (*dvml*) include two types. The first comprises very thin bands which run from the dorsal longitudinal to the ventral longitudinal muscles near the posterior segmental lines of the three thoracic and the first seven abdominal segments. The second consists of shorter muscle groups occurring near the middle, or slightly forward, of each lateral half of the second and third thoracic and first eight abdominal segments and attached at either end a short distance from the longitudinal muscles of the dorsal and ventral sets. In the last two thoracic segments the muscles of the latter set consist of only one or two large fibers, while in the abdominal segments the bands are much wider, becoming a little narrower in their upper attachment.

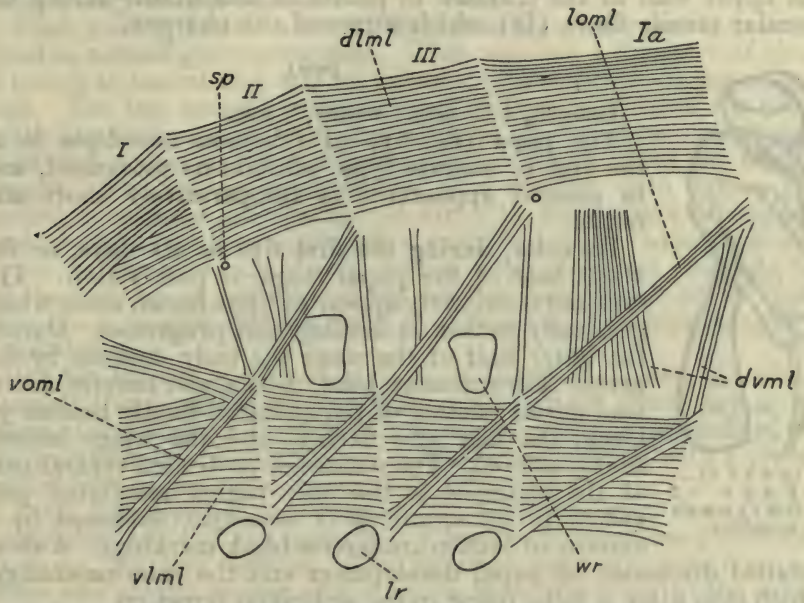


FIGURE 10.—*Chelonus annulipes*, last-stage larva: Integumentary muscles of three thoracic (I–III) and first abdominal (Ia) segments. *dlml*, Dorsal longitudinal muscles; *dvml*, dorsoventral muscles; *loml*, lateral oblique muscles; *lr*, rudiments of leg; *sp*, spiracle; *vlml*, ventral longitudinal muscles; *voml*, ventral oblique muscles; *wr*, rudiments of wing

The muscles of the head region are shown in Figure 7, B. The largest muscles found in the head of a Chelonus larva are those of the mandibles (*md*) and consist of two sets, the extensors (*1*), attached near the outer base of the mandibles and spreading toward the lateral wall of the head, and the flexors (*2*), originating at the inner base of the mandibles and extending laterad in a fanlike form. The sets are about the same size.

Two sets of muscles (*3*), arising near the antennal rudiments (*ant*), approach each other on the lower margin of the labrum. The labium is equipped with two sets (*4*), which are attached somewhat apart near the lower edge of the mouth (*mth*) and extend ventrally to converge in the region of the common silk duct opening (*slkdo*). A pair of muscles (*5*), located more ventrally in the labial region, probably functions in connection with the silk duct opening.

Two sets of rather narrow muscles (*6*, *7*) are found in each of the maxillary regions. Both of these continue laterad, and the upper one also extends dorsad toward the base of the mandibular muscles.

From the middle of the internal crosspiece of the tentorium (*ten*) at the back of the head, a short and rather wide muscle (*8*) is attached somewhat forward to the under wall of the esophagus. A little to each side, another set of short muscles (*9*) also unites the under part of the esophagus with this crosspiece, and near the point of attachment to the bar, two long muscles (*10*) are affixed and extend out in a laterad and cephalad direction. On either side of the labium, near its lower edge, a set of muscles (11) proceeds laterad to the body wall. A number of upright muscles (12) extend from the upper wall of the cranium to points of attachment among the circular muscle fibers (13) which surround the pharynx.

PUPA

FIGURE 11.—Pupa of *Chelonus annulipes*

Length, 4.75 mm.; width, 2 mm.

The pupa (fig. 11) of *Chelonus annulipes* is of the free or exarate type, exhibits no movement, and in general appearance is comparatively short and robust.

Its color, during the first five or six days, or for about half of the pupal stage, is pale yellow. The eyes and ocelli early appear as light-brown areas which gradually darken as development progresses. During the latter half of the stage the body darkens by degrees. The antennae, head, thorax, and heavily chitinized dorsal portion of the abdomen finally become jet black, the legs also darken, and the wings become smoky colored. The somewhat protruded ventral part of the abdomen is the only region remaining pale yellow in color, and it is somewhat darkened by a number of broken transverse black markings. A more detailed discussion of pupal development and the exterior changes which take place is to be found in the section on pupation.

Luginbill (*4*) has published a ventral view of the pupa of *C. texanus*.

COCOON

Length, 8 mm.; greatest width, 3 mm.

The cocoon (plate 1) of this species is thin and almost papery in appearance. It is cylindriform, roughly oval in shape, with the ends sometimes rather squared, and is somewhat thickened at the middle by a considerable number of circular threads which give it the appearance of being girdled by a narrow white band. It is constructed of glistening white threads loosely spun exteriorly but more tightly woven toward the interior and is attached by the outer threads either to the walls of the host tunnel or, as is more often the case, to the silken web made by the host larva during the latter part of its life. Through the cocoon the pupa in its different stages of development is dimly visible, and the cast meconium is seen pushed against the caudal extremity.

Generally the head and dried skin of the host larva are included in the outside web work, where they are attached at various points on the cocoon. In an examination of 54 cocoons from the field, the host head capsule and skin were found fastened to the cephalic end of 17 cocoons, to the caudal extremity of 25 more, and near the middle of 12 others.

BIOLOGY

METHODS OF REARING

The writer did not attempt to develop, to any degree, a method suitable for large-quantity production of this parasite; his aim was to rear only sufficient numbers to permit a study of the biology and morphology of the species.

Each male or female adult of Chelonus, upon emergence, was confined in a small glass-globe cage. This cage had a diameter of about 3 inches at the middle, and an opening of 2 inches diameter at each end. The top opening was provided with a removable tin cover, while the bottom was set upon a piece of strong white cloth tightly stretched across a 5-inch square wooden frame about an inch in height. The arrangement of the cage on the cloth frame permitted a constant interchange of air with the outside atmosphere and at the same time provided a suitable base to which the cage could be attached. A strong rubber band stretched over the top of the cage cover and around the wooden base united all so firmly that the cage with its base could be moved about without danger of overturning.

On the bottom of each cage, i. e., on the cloth frame, was placed a small 1-inch square of paraffined cardboard on which lay a half lump of dry sugar. Food in this form proved very convenient, and the parasites fed readily upon it. Water was applied with a pipette to the sides of the cage, usually only once a day.

Both honey-water and sugar-water solutions were found to be acceptable foods of the parasite. These foods were less convenient, however, for two reasons: They required constant changing; and there was always danger of the adults becoming stuck in the syrup.

In the writer's experiments, the male and female of *Chelonus annulipes* seemed to copulate most readily in the end of a 4-inch glass vial held toward a source of strong light. Mating in a globe cage was secured several times and at least once in a square box cage. None of the methods used proved certain, however, and many attempts to secure mating resulted in failure.

Oviposition was obtained by placing a mass of Pyrausta eggs on the floor of the female's cage. As a rule, the mass was attached to a small square of dock or corn leaf which, in turn, was glued to a piece of paper to prevent curling up. After the host eggs had been left exposed for a sufficient period, usually about 24 hours, the mass was removed and placed in a small glass-covered tin box with a few leaves of green dock. The borer larvae, on hatching, were allowed to feed on green dock leaves until they had reached the fourth instar. Each larva was then isolated in a 3-inch glass vial plugged with cotton and given more substantial food. When available, small pieces of green cornstalk were used as food for these older larvae; at other times portions of green fennel plant or

string beans served as nourishment. Chelonus cocoons spun in the glass vials [4] were left in the vials and placed in controlled temperatures for pupation and adult emergence.

The host larvae were kept at a constant temperature of either 68° or 77° F. The latter temperature was decidedly more favorable for the development of both host and parasite. Some parasitized larvae were also kept in an outdoor insectary during March, April, May, and June at Hyères, France. Under these last conditions, however, development of both the Pyrausta and Chelonus larvae was greatly retarded by cool and changeable weather.

OVIPOSITION

The female of Chelonus deposits her eggs within those of *Pyrausta nubilalis*. The eggs are laid singly, and as a rule only one is placed within an egg of the borer. At times, however, especially when an insufficient supply of host eggs is provided, a female will deposit a larger quota per egg. On one occasion 22 Chelonus eggs were dissected out of a mass containing only 5 eggs of the borer. Many later dissections of single Pyrausta eggs or newly hatched larvae have shown that more than one parasite egg was deposited in each. As many as 5 Chelonus eggs have been removed from one small host larva, and 2, 3, and 4 eggs per host egg have been observed at different times.

It is thought that the presence of several Chelonus eggs in a single Pyrausta egg means the death of all but one of them. It may be, however, that the eggs sometimes hatch while only one of the resulting larvae survive. This, of course, is often the case among internal-feeding hymenopterous parasite larvae. Never, during the course of great numbers of dissections, has more than one larva of Chelonus in any stage been observed.

Neither a preoviposition period nor mating is essential to egg laying. Upon emergence from the cocoon the female has within her ovaries a number of well-developed eggs which she will deposit at once if provided with host material.

It requires but a few minutes for a female of *Chelonus annulipes* in a small cage to locate a Pyrausta egg mass. Running about the cage, when she approaches within an inch or two of the egg mass she immediately senses its presence. This seems to excite her, and she waves her antennae rapidly about, drawing nearer to the eggs. The antennae are lowered, and with the tips flattened against the leaf surface they are pushed forward until they encounter the egg mass. The female then brushes the flattened tips of her antennae over the surface of the eggs, draws her body directly forward a short distance until her unsheathed ovipositor finds the spot just sensed by her antennae, and inserts her ovipositor vertically into one of the eggs.

During the actual laying of an egg the female stands over the host egg mass, her entire body quite motionless, the antennae extended straight out before her or bent slightly downward. The

[4] Glass vials open at both ends and plugged with two cotton stoppers would be preferable to the ordinary vial open at only one end. It would then be easy, when a Chelonus larva is spinning its cocoon in the proximity of a cotton plug, to remove the cotton from the opposite end and take out the remaining vegetable matter (which quickly decays) without in any way disturbing the parasite larva.

Cocoon of *Chelonus annulipes*

first movements following the deposition of an egg are a withdrawal of the ovipositor and a slight vibration of the antennae, after which the female turns around or goes to the other side of the egg mass before repeating the process. This proceeding may go on for some time, until seemingly every egg in the mass has been parasitized or the female has deposited all of the mature eggs which her ovaries contained.

The characteristic feeling of the surface of the eggs with the antennae and the moving forward of the body just prior to oviposition have been mentioned by Pierce and Holloway (*9*) in speaking of the parasitizing of egg masses of *Laphygma frugiperda* by *Chelonus texanus*, and Luginbill (*4*) has similarly described the oviposition of the same species in eggs of Laphygma.

The time required for the deposition of an egg by *Chelonus annulipes* varies, but in the case of a regularly ovipositing female it lasts usually from 15 to 30 seconds. The process often consumes several minutes, however. One female on her first day of oviposition was observed to deposit 16 eggs, spending an average of 1 minute and 40 seconds at each deposition. A maximum of 4 minutes and 30 seconds was required for one deposition, and a minimum of only 20 seconds for another. One day later this same female averaged 15 seconds per egg. On another occasion she oviposited ten times, using an average of 28 seconds for each egg, while she required only 10 seconds for depositing each of 6 other eggs.

Pierce and Holloway (*9*) observed that "less than a minute" was required for *C. texanus* to oviposit within an egg of *Laphygma frugiperda*. A few seconds to one-half minute or more is given by Luginbill (*4*) as the length of time that the ovipositor of the same species of Chelonus is retained within a Laphygma egg, and Vickery (*16*) gives four seconds for the oviposition of the same species and host. Luginbill speaks of 1 female of *C. texanus* ovipositing 13 times in 35 minutes at a temperature of 72° F., and of another individual ovipositing eight times in 1 minute and subsequently five times in a like period of time, and records that on 2 occasions the act of oviposition required only about 5 seconds.

The writer is of the opinion that the first ovipositions of a female of *C. annulipes* are sometimes of slightly longer duration than are those which follow when the insect is regularly depositing her normal quota of eggs.

The female of this species will oviposit in Pyrausta eggs of all ages, from fresh to mature. Apparently the age of the host egg does not influence the choice of the female nor the development of the parasite. Chelonus have been reared to the adult stage from eggs deposited in host masses which varied in age from a few hours to five days.

Table 4 presents the data obtained in a study of the oviposition of a Chelonus female in host eggs of several different ages. A number of corn borer egg masses, each differing in the maturity of the embryo which it contained, were exposed at the same time and for a 24-hour period to a female parasite. The eggs from each mass were then carefully dissected and the parasite eggs counted. The data so secured, together with other information obtained, seem quantitatively sufficient to warrant the conclusions drawn in the above

paragraph. The distribution of the eggs was, of course, somewhat dependent on chance, as the female would usually utilize those host eggs which she first encountered and might deposit a considerable number of her eggs before searching for other host material.

TABLE 4.—*Oviposition of one female Chelonus annulipes in Pyrausta eggs of different ages, 1930*

Date	Age of Pyrausta eggs								Total	
	Fresh		1 day old		2 days old		3 days old			
	Host eggs exposed	Parasite eggs deposited	Host eggs exposed	Parasite eggs deposited	Host eggs exposed	Parasite eggs deposited	Host eggs exposed	Parasite eggs deposited	Host eggs exposed	Parasite eggs deposited
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Apr. 5	11	6	12	10	19	15			42	31
Apr. 6			14	6	19	16	30	28	63	50
Apr. 7	14	7	11	11	10	13	11	13	46	44
Apr. 8	11	1	15	11	18	20			44	32
Apr. 9	23	10	15	3			24	8	62	21
Apr. 10	11	10	21	10	21	7			53	27
Apr. 11	7	6	12	2	22	0	15	4	56	12
Total	77	40	100	53	109	71	80	53	366	217

The studies summarized in Table 5 tend to prove that the larval and pupal development of the parasite is not decidedly influenced by the age of the host egg in which the female oviposits. There was found little variation from the averages of a larval period of 23.2 days, a pupal period of 9.3 days, or a total larval-pupal period of 32.5 days in parasites resulting from oviposition in host eggs of different ages.

TABLE 5.—*Effect of age of Pyrausta egg masses upon length of larval and pupal periods of Chelonus annulipes at 77° F.*

Pyrausta eggs	Larval period		Pupal period		Average length of combined larval and pupal period
	Individuals	Average length	Individuals	Average length	
	Number	*Days*	*Number*	*Days*	*Days*
Fresh	8	26.5	5	7.2	33.
1 day old	6	23.0	3	8.3	31.3
2 days old	8	20.0	4	8.0	28.0
3 days old	8	25.4	2	11.5	36.9
4 days old	33	22.3	16	10.4	32.7
5 days old	3	21.7	3	10.3	32.0
Total or average	66	23.2	33	9.3	32.5

Observations made during the experiment just cited further confirm the conclusion drawn therefrom. Frequently the female was watched as she deposited a number of her eggs in an egg mass of a certain age and then passed to a second mass, or several others, more or less mature, and there continued her oviposition as before. An ovipositing female was even pushed with a brush from one egg mass to another of different age without interfering with the process of egg laying.

It has sometimes seemed to the writer that there existed a slight aversion on the part of the female to eggs which were within a few hours of hatching. It may be that the movements of the larvae within such eggs are distasteful to her. Females showed no inclination to oviposit in the newly hatched corn-borer larvae.

In an attempt to learn the egg-laying capacity of *Chelonus annulipes* an unmated female was confined in a small glass cage, kept at a room temperature of about 75° F., and supplied with a new mass of corn-borer eggs every 24 hours. The host eggs ranged in age from one to three days, and at the end of each day they were dissected for a count of the parasite eggs. As shown in Table 6 this female lived 25 days and deposited a total of 655 eggs in 22 days, or an average of 29.8 eggs per day. Her maximum daily oviposition was 65, and her minimum eight. After death her ovaries were dissected, and 156 well-developed eggs were found. Thus this female produced 811 eggs, and it was noted that her ovaries were still in excellent condition and oögenesis was going on at a normal rate.

TABLE 6.—*Daily oviposition of unmated female*[1] *of Chelonus annulipes at room temperature, 1930*

Date	Number of eggs	Date	Number of eggs	Date	Number of eggs
June 7	22	June 15	28	June 23	49
June 8	21	June 16	19	June 24	29
June 9	16	June 17	29	June 25	41
June 10	22	June 18	36	June 26	31
June 11	21	June 19	20	June 27	8
June 12	9	June 20	52	June 28	52
June 13	40	June 21	26		
June 14	19	June 22	65	Total	655
Average per day					29.8

[1] Emerged June 6; died July 1. No eggs oviposited during last 3 days of life.

The oviposition of four mated females of Chelonus on certain days is given in Table 7. The most striking point illustrated is the enormous number of eggs (165) deposited by female 3 on April 24. This parasite had not been supplied with host eggs during the previous nine days and the indication is that a considerable number of her eggs had matured within the ovaries and were ready for deposition at the first opportunity. On April 8 female 1 laid a total of 89 eggs.

TABLE 7.—*Intermittent*[1] *oviposition of four mated females of Chelonus annulipes, 1930*

Date	Eggs deposited by—			
	Female 1, emerged Mar. 17	Female 2, emerged Mar. 17	Female 3, emerged Mar. 28	Female 4, emerged Apr. 7
	Number	*Number*	*Number*	*Number*
Apr. 5	----------	39	53	----------
Apr. 6	----------	50	36	----------
Apr. 7	28	44	54	----------
Apr. 8	89	35	----------	56
Apr. 9	----------	21	----------	----------
Apr. 10	----------	25	----------	20
Apr. 11	----------	12	----------	14
Apr. 15	----------	----------	35	----------
Apr. 24	----------	----------	165	----------

[1] On those days showing no oviposition host eggs were not exposed to the females.

Four other mated females, kept under laboratory conditions and provided with host eggs at intervals, deposited 231, 343, 393, and 273 eggs during life periods of 27, 72, 39, and 65 days, respectively. In no instance were the females in a position to oviposit continually, and all eggs exposed were not dissected. The figures only demonstrate that from 200 to 300 eggs may easily be deposited by a female whose capacity for egg deposition probably is twice as great, and whose life may be prolonged more than two months.

One Chelonus female was confined in a cage and supplied with host eggs daily from March 6 to 21. In Table 8 the results obtained are summarized. In all a total of 1,807 host eggs were exposed to parasitism, and a hatch of 63 per cent was obtained. Certain of the parasitized larvae which hatched were reared until the Chelonus issued, whereas others were dissected and the presence of the parasite noted. With such a procedure 12.4 per cent of the original Pyrausta larvae were definitely established as parasitized. This female lived 65 days.

TABLE 8.—*Data on daily oviposition of one female*[1] *Chelonus annulipes in eggs of Pyrausta nubilalis, 1930*

Date	Host eggs exposed	Age of host eggs	Host larvae hatched	Chelonus larvae issued from host larvae	Chelonus eggs and larvae dissected from host larvae	Total Chelonus produced	Parasitism of host larvae
	Number	*Days*	*Number*	*Number*	*Number*	*Number*	*Per cent*
Mar. 6	23	5	23	4	6	10	43.5
Do	174	4	134	25	6	31	23.1
Mar. 7	87	4	54	3	4	7	12.9
Mar. 8	87	4	54	4	0	4	7.4
Mar. 9	146	4	123	9	5	14	11.4
Mar. 10	119	2	88	7	3	10	11.4
Mar. 11	77	3	47	9	0	9	19.1
Mar. 12	92	1	40	0	2	2	5.0
Mar. 13	103	1	79	6	3	9	11.4
Mar. 14	116	3	46	1	8	9	19.6
Mar. 15	122	3	65	12	1	13	20.0
Mar. 16	98	3	56	13	0	13	23.2
Mar. 17	174	4	136	0	5	5	3.7
Mar. 18	63	5	24	2	1	3	12.5
Mar. 19	93	2	43	0	0	0	0
Mar. 20	110	2	68	0	0	0	0
Mar. 21	123	2	58	1	1	2	3.4
Total	1,807		[2] 1,138	96	45	141	12.4

[1] This female was mated, but the fact that all of her progeny reared to the adult stage were males strongly indicates that fertilization did not occur.
[2] Equals 63 per cent of the total number.

The material to which host eggs are attached does not influence the female in her impulse to deposit eggs. Females were observed to oviposit with equal readiness in unattached eggs or masses of eggs on leaves of dock or corn, or on paper.

It was also learned that the position of the host eggs does not affect oviposition by the parasite. Oviposition was effected equally as well in eggs placed horizontally on the bottom of a cage, upside down on the inner surface of the cage top, or hanging in a vertical position in the middle of the cage. All Pyrausta eggs in the field,

so far as their position on the leaves of the corn plants is concerned, may therefore be considered subject to parasitism by Chelonus.[5]

LARVAL DEVELOPMENT

With *C. annulipes*, as with other hymenopterous parasites whose larvae feed internally, it is difficult to follow closely the larval development. Many daily dissections of parasitized host larvae of various ages are necessary, and in addition the individual differences in the size of each parasite larva as influenced by the variations in their host environment enter to complicate the problem. However, from a considerable number of dissections, coupled with a study of the parasite larvae in relation to body size, head width, molted skin, etc., a general idea of the advancement of the larva may be obtained.

Dissections of 46 Pyrausta larvae of different ages containing Chelonus parasites kept at a constant temperature of 77° F. showed the length of the larval stages to be approximately as follows: First stage, 15 days; second stage, 3 days; last stage (internal), 1 day; last stage (external), 1 day; total, 20 days.

It is true, of course, that a considerable individual variation occurs in the length of the stages, and the above figures are no doubt somewhat low for the development of first-generation parasite larvae in the field during June and early July, when the cool nights would tend to slow up growth. Probably the average length of larval life in the region of St. Giorgio di Nogaro in the first generation is between 20 and 30 days, those larvae developing latest making the most rapid growth in the more intense heat of midsummer.

The Chelonus larva of the second generation spends nearly nine months of the year in an advanced condition of the first-stage larva within the hibernating host. In both generations the last two stages seem to be of comparatively short duration.

In a study of the total larval period (all stages) in host larvae kept at a constant temperature of 77° F., data on 82 individuals showed the average larval period to be 23.2 days, with a maximum of 34 days and a minimum of 15 days.

In one lot, at this temperature, from which 66 Chelonus larvae issued, the average length of time elapsing between the deposition of the parasite egg and issuance of the larva from the host was 22 days. Pupation of 50 unparasitized host larvae reared at the same time, counting from the time that the eggs were exposed to oviposition by Chelonus until the pupae were formed, required an average of 28.8 days. In other words the Chelonus larvae left their hosts on an average 6.8 days earlier than the latter normally pupated.

Similar information on larvae reared at a temperature of 68° F. is more limited. This is due to the difficulty of rearing Chelonus at the lower temperature. At 68° the host itself grew more slowly, and to an even greater degree the development of the parasite was

[5] It occurs to the writer, however, that under actual field conditions the female Chelonus, in an effort to escape the intense heat of the sun's rays, may remain much of the time on the shady under surface of the corn leaves and probably oviposits more in egg masses which are found on that part of the plant. Oviposition, under such circumstances would, for the most part, take place with the female parasite clinging to an under surface or in a partly vertical position. Should such be the case these conditions would be favorable to the propagation of the species, as most of the corn-borer eggs themselves are attached to the under surface of the corn leaves.

retarded. Mortality among both parasitized and unparasitized corn borers was also fairly high. In fact, out of a total of at least 150 Pyrausta larvae from eggs exposed to the parasite, less than 10 per cent survived at the end of two months, and last-stage Chelonus issued from only two of the surviving larvae. From time to time various host larvae were dissected, with results as given in Table 9. Some of the Chelonus larvae, more than 2 months old, had not advanced beyond the late first stage. Of the 2 full-grown larvae which issued, 1 had lived 35 and the other 51 days within the host.

TABLE 9.—*Rate of development of larvae of Chelonus annulipes within host larvae kept at 68° F.*

Parasite larvae observed	Age of parasite larvae when observed	Stage of parasite larvae when observed	Parasite larvae observed	Age of parasite larvae when observed	Stage of parasite larvae when observed
Number	*Days*		*Number*	*Days*	
1	14	Late first.	2	37	Late first.
1	16	Do.	1	42	Do.
1	17	Do.	1	51	Last, just issued from host.
1	19	Do.	1	58	Late first.
5	31	Do.	1	59	Do.
1	35	Last, just issued from host.	1	62	Do.
1	36	Late first.			

In rearing work it was found that Pyrausta larvae parasitized by Chelonus, after a certain amount of feeding on either string beans or fennel plant, usually left their food and surrounded themselves with a light web work of threads, soon became plump and more or less curved dorsoventrally, and developed an appearance similar to that of an undersized prepupa. Within 24 to 48 hours Chelonus larvae issued from such borers. The host larvae did not invariably leave their food before spinning up, and a few Chelonus issued from borers still in the tunnels of the plant upon which they were feeding. The excessive moisture present in the vegetable matter was no doubt responsible for the crawling out of the host larvae after the stimulus for further feeding had ceased.

In addition over 100 young Pyrausta larvae which had been exposed to parasitism by Chelonus during the egg stage, were isolated in vials and subjected to the temperature of an outdoor insectary at Hyères, France, during the period April 2 to June 30, 1930. Many of the nights during the above period were uncommonly cool and the daily temperature was often lowered by cloudiness and frequent rains. Under these conditions the growth of both parasite and host was slow, and (as indicated in Table 10) 70 days elapsed before a Chelonus larva issued from one of the hosts. Even after 88 days two of the parasite larvae were still in the late first stage.

ISSUANCE AND EXTERNAL FEEDING OF LAST-STAGE LARVA

Soon after its molt into the last stage, the larva of *Chelonus annulipes* (with the anal vesicle now withdrawn into the body cavity where it forms the hind intestine) makes with its mandibles an opening in the host integument and pushes its head and body segments through.

TABLE 10.—*Rate of development of larvae of Chelonus annulipes within host larvae kept in outdoor insectary between April 2 and June 30, 1930, at Hyères, France*

Parasite larvae observed	Age of parasite larvae when observed	Stage of parasite larvae when observed	Parasite larvae observed	Age of parasite larvae when observed	Stage of parasite larvae when observed
Number	*Days*		*Number*	*Days*	
1	53	Late first.	1	76	Last, just issued from host.
3	57	Do.	2	77	Do.
3	68	Late first, 1; second, 2.	1	79	Do.
1	70	Last, just issued from host.	2	88	Late first.
1	74	Do.			

Within the body cavity of the corn borer, the Chelonus larva has been lying with its head oriented cephalad of the host, and, just prior to issuance, at least, has had the ventral part of its body against the dorsal wall of the host larva.

According to the writer's observations it issues from the dorsal side of the host, and usually in the region of the first to third abdominal segments. The exact point of exit is apparently dependent upon the relation between the length of the parasite larva and that of the host larva. In 15 observations, issuance in 9 cases was from the region of the first or second abdominal segment and in the other 6 from a point near the third abdominal segment.

The parasite larva works its body out rather quickly. This is accomplished by a squirming motion assisted by a bending of the exposed segments back toward the posterior end of the host, thus forming a sort of fulcrum at the point of exit. All but the last one or two of the abdominal segments are withdrawn; these remain within the host until external feeding has been completed. However, the larva is able to continue its feeding if the anal segments are entirely freed.

As soon as most of the body segments are outside, the parasite makes an incision with its mandibles at some point near the caudal extremity of the host and begins its external feeding. Such feeding generally continues for about 24 hours, although it is sometimes finished sooner. The larva feeds in a curled position until the host has been entirely exhausted and nothing remains but the chitinous head parts and the empty skin. During the feeding the mouth parts are frequently withdrawn and fresh incisions made at other points of the host's body.

In one instance divergence from the usual method of issuance was noted. In this case the parasite larva came out on the dorsal side in the region of the sixth abdominal segment of the host larva, and finally was observed entirely free, feeding at the exit hole. It seems that this Chelonus larva issued so near the posterior end of the Pyrausta larva that on bending its body caudad of the host, it found no food. In an attempt to move in some other direction toward a source of food, its anal segments became dislodged, and the open exit hole provided an immediate feeding point.

Practically all of the blood and internal organs of the Pyrausta larva are devoured, and within the peritrophic membrane of a Chelonus larva that has just finished its external feeding are to be

found rather large pieces of the host tracheae, parts of the severed nerve ganglia, fat, blood cells, and other parts of the internal organs.

The effect upon the parasite larva of this external feeding is quite noticeable in the more rounded and plump contour of the body and a darkening of the contents of the peritrophic membrane from a pale-yellowish to a rather dark-brown color, which affects the general coloration of the larva.

SPINNING OF COCOON

The cocoon (plate 1) is constructed of slender white threads secreted by the silk glands of the last-stage larva, and pressed out through the external opening of the common silk duct located on the upper border of the labium. The spinning process is begun very soon after the completion of the external feeding of the last-stage larva, and the construction of the cocoon requires from 12 to 24 hours.

During the spinning the head of the parasite is moved back and forth and up and down, and the threads, at first attached to the surrounding medium, are gradually woven into a cocoon. The silk is stretched in various directions, and in its viscous state is attached at different points by the pressure of the mouth of the larva, after which it dries and hardens. Within the framework so designed spinning is continued, and more threads are added until the structure is so thick that one is able to see the larva only by transmitted light. The head capsule and cuticle of the last-stage host larva are more or less incased in the outer web work of the cocoon.

Without having fed externally upon the host larva, the last-stage larva of Chelonus appears unable to construct a cocoon. In one instance the newly issued larva was removed from the host before it had the opportunity to feed externally, and was placed in a cotton cell, where it lived for over a week. This larva apparently had the impulse to spin, and a considerable quantity of thread was pushed out of the opening of the silk duct. All of the thread, however, was amassed in a sort of ball in the head region of the larva; the parasite seemed incapable of moving its body to attach the thread in the formation of a cocoon.

If a Chelonus larva, after it has completed its external feeding, is disturbed in any way, it is unable to construct a cocoon. This has been observed numbers of times. Such larvae, when deliberately removed from their normal position in the silken web of the host and placed in a cotton cell, would spin a few threads but were never known actually to construct a cocoon. A similar reaction took place in the case of larvae which were moved about in vials at the time that they were ready to spin. Those larvae which were unable to spin their cocoons were never known to pupate normally.

Vickery (*16*) has observed that *Chelonus texanus* will not complete its cocoon unless the larva is inclosed in a cell. That species, however, sometimes pupated within an incompleted cocoon.

PUPATION

The pupa of *Chelonus annulipes* lies largely in the posterior two-thirds of the cocoon, with the tip of its abdomen more or less sub-

merged in the semiliquid larval meconium which is pushed against the inside wall of the cocoon at its caudal extremity. It is the writer's opinion that the water content of the larval meconium is responsible for a degree of humidity within the cocoon which is beneficial to the pupa.

The pupal period actually starts upon completion of the last larval molt, which takes place from 12 to 24 hours after the casting of the larval meconium. For some hours previous the insect has been in the intermediate state of prepupa. With a parasite like Chelonus, however, it is not easy to determine by observation of the cocoon just when the prepupal stage has terminated and the last larval molt occurred. One is able, however, through the semitransparency of the cocoon, to see the cast meconium, and it is this point which for practical purposes has been taken to indicate the beginning of the pupal period. The time of actual emergence of the adult from the cocoon has been designated as the end of the pupal period, although, strictly speaking, the transformation from pupa to adult has actually taken place a short time before the exit of the parasite.

The lengths of the pupal period at several controlled temperatures, as given in Table 11, were determined from a study of 76 individuals upon which daily observations were taken.

TABLE 11.—*Length of pupal period of Chelonus annulipes at various temperatures*

Temperature	Pupae	Length of pupal period [1]		
		Average	Maximum	Minimum
° F.	*Number*	*Days*	*Days*	*Days*
64	10	23.0	28	21
68	20	20.4	24	16
77	46	9.5	14	5

[1] The pupal period is considered as the length of time between the casting of the larval meconium and the emergence of the adult from the cocoon.

The effect of temperature upon the development of the pupa is quite evident. The average lengths of the pupal stage at constant temperatures of 64° and 68° F. were 23 and 20.4 days, respectively, both periods being more than twice as long as the 9.5 days required at 77°. Maximum and minimum temperatures varied accordingly.

A low temperature of 46° F. serves to retard pupal development, and it has been strongly indicated that a too long exposure to such cold results in a high mortality. During the summer of 1929, 48 Chelonus cocoons containing prepupae or early pupae, collected in Italy and brought direct to Hyères, France, in cold storage, were placed in a refrigerator at a constant temperature of 46° . Examination of these cocoons one month and a half later showed that within 33 of them the pupae had become black and were well developed, while in 12 others they were still yellow and in an early stage. Three of the latter individuals had died as larvae without pupating. Twelve of the late-stage pupae were placed at a temperature of 77°, and two adults emerged a few days later.

At another time five individuals of Chelonus, as soon as they had pupated, were exposed to a temperature of 46° F. Upon removal from this temperature one month and a half later the pupae within the cocoons appeared yellow and still in a comparatively early stage. They were placed at 77°, and two male adults emerged six days later. It may, then, be stated that the pupal period in a few cases, at least, lasted for approximately a month and a half, at 46°, but that the total emergence under such conditions was poor. Many more quantitative experiments than the writer has been able to undertake are essential for the determination of the exact length of time that Chelonus pupae may be subjected to a low retarding temperature, and still allow a satisfactory emergence of adults when the cocoons are exposed to a higher temperature.

Daily observations were made on a number of Chelonus pupae removed from their cocoons after the completion of spinning and kept continually at a temperature of 77° F. The average rate of development was determined as follows:

First day. Meconium cast and parasite remains as prepupa for 12 to 24 hours. The prepupa is pale yellow in color, with the eyes showing a light brown. Best described as the stretched-out last-stage larva. It is quite motionless.

Second day. Skin of last-stage larva has been shed. Pupa light yellow in color. Brown eyes and ocelli can be seen.

Third day. Little change except a darkening of the brown of the eyes and ocelli. Differentiation of the pupal segmentation and a general darkening of the yellow of the body.

Fourth day. Further darkening of eyes and ocelli, and of body in general.

Fifth day. First thoracic segment darkening to a black color. Mandible tips light brown.

Sixth day. Head and all of thorax black. Mandible tips dark brown. Wings, antennae, and legs still white.

Seventh day. Abdominal sclerites also black. Upper part of legs darkening. Drop of dark yellow fluid excreted in anal end of pupal skin.

Eighth day. Pupa all black except soft light yellow abdomen.

Ninth day. Adult issues from pupal skin and casts pellets and pupal meconium.

It is also of interest, as well as of certain practical value, to be able to estimate the development of the pupae of *C. annulipes* from an examination of the cocoons. This may be accomplished by viewing the color of the pupa through its cocoon. In Table 12 are listed the writer's observations on 14 cocoons kept at a constant temperature of 77° F. and examined daily during the entire pupal period. On an average, the pupa of *C. annulipes* appeared pale yellow in color for five or six days after the casting of the larval meconium. In three instances the pupa remained in this condition for a maximum of seven days, while in two cases it became black on the fourth day.

It was found that from the day when the pupa appeared black, an average of 6.7 days elapsed before the emergence of the adult insect from its pupal skin. This period, in the case of one individual, required a maximum of eight days and in another a minimum of only five days. Seven days were needed in each of six of the observations.

TABLE 12.—*Approximation of pupal development within the cocoon of Chelonus annulipes at a constant temperature of 77° F.*

Individual No.	Period from casting of larval meconium until pupa appears black through cocoon	Length of period from time pupa appears black through cocoon until emergence of adult	Total length of period from casting of larval meconium to emergence of adult
	Day	*Days*	*Days*
1	Fifth	7	12
2	Fourth	5	9
3	Fifth	6	11
4	Seventh		
5	do		
6	Sixth	7	13
7	do	8	14
8	do	6	12
9	Fourth	7	11
10	Fifth	7	12
11	Sixth	7	13
12	do		
13	Seventh	7	14
14	Fifth		
Average	Fifth–sixth	6.7	12.1
Maximum	Seventh	8	14
Minimum	Fourth	5	9

It should be borne in mind, however, that the writer's figures are based only on cocoons kept at a constant temperature of 77° F. Higher or lower temperatures would tend to shorten or lengthen the pupal period, and consequently affect the appearance of the pupa.

Nevertheless, daily observations on pupae under definite conditions will give some idea of development. For instance, yellow pupae indicate an early stage, and black pupae show an advancement which will soon result in adult emergence. When the antennae and legs of the adult are seen to be free from the pupal skin and slight movements of the insect are taking place, it is certain that the pupal skin is nearly or entirely shed and that the adult will emerge soon. Shortly before emergence the adult usually moves somewhat forward in the cocoon and voids a number of small spiral pellets of excretory material and a small pupal meconium containing, for the most part, the broken-down mid-intestine of the last-stage larva.

EMERGENCE OF ADULT

When ready to emerge, the adult Chelonus tears with its mandibles an irregular opening near the anterior end of the cocoon through which it forces the body. Behind, in the other extremity of the cocoon, it leaves the molted skin and the cast meconium of the last larval stage. The adult after its exit from the cocoon is quite dry and at once moves about in a lively manner.

The following observation of the emergence of a male Chelonus made under the binocular microscope is typical of the procedure:

Through the somewhat transparent texture of the thin, white cocoon can be discerned the black adult with its abdomen pulled slightly away from the cast meconium and its head not far from the anterior end of the cocoon wall. The antennae and legs have been freed from the body and frequent movements of these appendages occur. The legs are more or less doubled under the body

and the insect pushes itself forward on its "knees" (joints of the femur and tibia) until its head rests close against the wall of the cocoon.

At this time, just 25 minutes after the start of the observation, the adult manifests more activity and moves its head about in several directions while its legs, which are now more stretched out, push the body strongly forward. Within five minutes the two chitinous mandibles have begun to move and the actual cutting of the exit hole has commenced. The mandibles go back and forth, tearing away the threads of the cocoon and after two minutes they have pierced the texture and pushed themselves outside. The tearing process continues until the insect, still pushing forward on its "knees," is able to thrust the head through. The head is again drawn inside of the cocoon, however, and a little more tearing with the mandibles is carried on for about a minute before the entire insect emerges. The actual tearing process of the mandibles has lasted exactly seven minutes.

In experiments in which three lots of cocoons were kept at a temperature of 77° F., the emergence of Chelonus adults was found to be 51.5, 60.8, and 65.5 per cent, respectively.

OCCASIONAL ABNORMALITY IN ADULT

It has been observed that at times the abdomen of a freshly emerged adult of either sex is somewhat swollen, protruding slightly beyond the chitinous exoskeleton, and in certain lots this condition has been extremely prevalent. The proper interpretation of this unusual condition would be an interesting study. The limited observations of the writer lead him to believe that the factor responsible for such abnormal swelling of the abdomen is an inability of the insect to expel a sufficient amount of excretory material accumulated in the body during the larval and pupal stages.

Normally, near the time when the pupa within the cocoon becomes black, a drop of dark-yellow fluid is excreted from the anus. A few days later the adult breaks through the pupal skin and lies free within the cocoon for some hours before tearing its way out. During this latter period the parasite expels, in the form of a long spiral or series of small spiral filaments, a considerable amount of a pasty material, rather fine in texture and pale yellow in color. As many as 50 of these filaments have been counted within a cocoon from which the adult had just emerged.

At other times adults emerge with distended abdomens and, after making their exit, cast pellets for a few hours. Sometimes part of the material has already been voided within the cocoon. In either case such parasites soon appear as normal as those which emerge after casting all of the excretory material inside of the cocoon.

Finally there are those individuals with decidedly extruded abdomens, that have cast little or nothing inside the cocoon and are unable to void anything after their freedom. In these, the distention of the abdomen persists, the individuals are weak, and death soon results.

PROPORTION OF SEXES

Under normal field conditions, in both the first and second generations of *C. annulipes*, as they occur in northern Italy, the proportion of the male and female sexes is probably about equal. An examination of 58 individuals which emerged from first-generation material collected in the field at St. Giorgio di Nogaro in July, 1929, showed the presence of 28 males and 30 females. Out of a lot of 53 individuals of the second generation of 1929 which issued from host larvae

collected during the late fall in the same locality, 27 were of the male and 26 of the female sex.

D. W. Jones, of the United States Entomological Laboratory, Arlington, Mass., has also found that the males and females bred from similar material occurred in a 50-50 ratio.

COPULATION

The copulation of individuals of this species of Chelonus may be secured under ordinary laboratory conditions. Although mating has been obtained several times by placing the male and female in a small box cage exposed to strong light, this method as a rule has given poor and inconsistent results. Often the male was quite attentive while the female would refuse all attentions.

The most satisfactory means of procuring fertilized females, so far found by the writer, is to place the two insects of opposite sexes in a 4-inch glass vial and allow them to approach each other in the closed end, which is held toward a source of strong daylight in a well-heated room. Under such circumstances the male becomes excited and pursues the female with antennae vibrating and wings whirring. Almost immediately he climbs upon her back and makes contact of the genital organs. The male then loses all hold of the female except that of the genital parts and lies more or less on his back while the female pulls away from him. The act of copulation lasts from 30 to 40 seconds, after which the two insects separate.

Certain females, even under the conditions described above, positively refuse to mate and prevent all attempts of the male to mount by a raising of their wings and a rapid retreat. Such refusal on the part of the female has been observed when she was placed with males of different ages and on various days.

The male often shows great interest in the female and attempts copulation as he pursues her with antennae waving and wings vibrating rapidly whenever he comes within her immediate vicinity. In certain instances, however, the male appears quite disinterested. It has been observed that a male will mate with more than one female and with only a few minutes' interval between the copulations, and that the female will sometimes permit a second mating.

K. Bartlett, of the United States Entomological Laboratory, Arlington, Mass., in working with large numbers of Chelonus, has observed mating at temperatures ranging from 62° to 88° F., with the largest proportion taking place from 75° to 80°. He has found that, although mating might occur at any time of day, the females were most susceptible in strong sunlight, and that to obtain a large number of matings at one time it was best to have present a preponderance of males over females in a 4-to-1 ratio. It is his belief that females which are three days old mate most readily.

PARTHENOGENESIS AND NONFERTILIZATION

The unfertilized female of *Chelonus annulipes* will oviposit readily, and her eggs will develop normally. In all known instances, however, the progeny from such parthenogenetic reproduction were males.

In the case of the mated female on which data have been given in Table 8, there was found an indication that apparently normal copu-

lation sometimes results in nonfertilization. This female emerged on the afternoon of March 5, and on the following morning a male 23 days old was placed with her. No interest was manifested on the part of either sex, and the male was removed. A younger male (only 6 days old) was then supplied, and after a few minutes copulation ensued. From the Pyrausta parasitized by this female during the following days, 49 adults of *C. annulipes* were reared, all of which were males. Although this is only an isolated case, it opens up a subject of considerable interest and one worthy of study.

REACTIONS OF ADULT

The adults of this species, being somewhat positively phototropic, are comparatively easy to handle in the laboratory. If, however, an individual is allowed to escape in a room some distance from lighted windows, it will pursue a zigzag course of flight toward the light and will come to rest several times on its way, sometimes in places that are somewhat shady or hidden. The tendency, though, is to approach the source of light. When isolated in a small globe cage, Chelonus shows little tendency to remain in that part nearest the light, but will walk or fly about in all directions and will often be found resting on the glass walls, at the bottom, or on the underside of the top of the cage.

The activity of the adult is largely dependent upon the temperature. At a steady cold of 46° F. the insect remains quiet a large part of the time. When subjected to constant temperatures of 64° and 68°, activity is increased, and at a temperature fluctuating around 68° a reasonable amount of activity is maintained. Under the last condition the parasite spends considerable time at rest, but moves about in search of food and water, or lingers over an egg mass depositing eggs. At a temperature above 68° it walks and flies about the cage much more rapidly than at the lower temperatures.

Like many other insects, the adult of *C. annulipes*, when suddenly disturbed, will " play dead." For example, when shaken from the top of the cage in which it is confined, the parasite will often land on its back or side with its antennae extended or bent back under the body, and will lie still as if dead. This motionless attitude is often maintained for several minutes, and in one instance the writer observed a female that remained perfectly still on her back for a period of nine minutes.

LONGEVITY OF ADULT

Normal individuals of *C. annulipes* are hardy insects and in optimum environment live for some time. In an effort to learn something of the relative length of life of the species, 90 freshly emerged adults at different times were subjected to various conditions of food, water, and temperature. Each individual, confined in a separate cage of the type already described, was given careful attention and observed daily until its death.

Table 13 presents the data resulting from such observations. The following remarks are explanatory of the tabulation. The temperatures of 46°, 64°, 68°, and 77° F. were electrically controlled and practically constant. The outdoor insectary used during February to May at Hyères, France, provided a rather cool temperature with normal daily fluctuations. Room temperature was that of the lab-

oratory where the average during the day was about 68°, becoming somewhat colder during the nights in the late winter and early spring months when the experiments were in progress. Food, in all cases, consisted of a half lump of dry loaf sugar placed on the cage bottom, and water was provided once daily in the form of drops on the inside of the glass walls of the cage.

TABLE 13.—*Records of longevity of adults of Chelonus annulipes kept under different temperature and food conditions*

Temperature	Length of life—								
	With no food or water		With food only		With water only		With food and water		
	Individuals	Average	Individuals	Average	Individuals	Average	Individuals	Average for males	Average for females
°F.	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*
46	7, 11, 13, 16	11.8	10, 11	10.5	14, 30, 33	25.7	15, 43	29.0	-------
64	2, 7, 10, 11	7.5	10, 12, 14	12.0	3, 10, 14	9.0	40, 51, 69	53.3	-------
68	5, 7, 9, 9	7.5	8, 9	8.5	5, 8	6.5	28, 37, 43, [1] 69, [1] 72	36.0	70.5
77	3, 3, 3, 3, 5	3.4	4, 5	4.5	3, 4	3.5	9, 11, [1] 30, 63	27.7	30.0
Outdoor insectary	3, 6, 7, 8	6.0	10, 11, 13	11.3	10, 13, 14	12.3	59, 68	63.5	-------
Room	4, 7	5.5	6, 6, 8, 10	7.5	5, 6, 9	6.7	12, 14, 20, 22, 25, 29, 32, [1] 39, 40, 41, 42, 43, 45, 46, 49, [1] 65, [1] 65, [1] 72, [1] 84	32.9	65.0
Total male individuals, number	23	------	16	------	16	------	27	-------	-------
Average longevity for males, days	----------	6.9	----------	9.2	----------	11.3	----------	36.9	-------
Total female individuals, number	----------	------	----------	------	----------	------	8	-------	-------
Average longevity for females, days	----------	------	----------	------	----------	------	----------	-------	62.0

[1] Females; all others are males.

The majority of the adults handled were males, and data were obtained on only eight females, all of which received both food and water. The life of these females kept at 68° F., at 77°, and at room temperature, varied from 30 to 84 days. The latter figure, attained at room temperature, was the maximum longevity for either sex under any given condition.

It is probably true in the case of this parasite, as in that of many others, that the longevity of the female exceeds that of the male insect (when both receive nourishment), and the data would seem to confirm this. In two instances the average longevity of the female was practically twice that of the male. For example, at 68° F. the average length of life of 3 males was 36 and that of 2 females 70.5 days, and at room temperature the average longevity of 32.9 days for 14 males, as compared with that of 65 days for 5 females. At 77° one female lived 30 days, whereas the average life of three males at the same temperature was 27.7 days. The maximum length of life for a male (at 64° with food and water) was 69 days.

Both food and water appear to be necessary for the prolongation of life longer than two weeks. With food alone or with water alone the longevity was somewhat greater than when neither was provided. Individual differences in this respect were not great, however, except in the cases of two individuals at the low temperature of 46° F. which lived 30 and 33 days, respectively, when water alone was supplied them.

Temperature did not play as important a part in relation to adult longevity as might have been expected. Perhaps the most noticeable evidence of its effect was in the shortening of the life of individuals kept at a temperature of 77° F., without food or water or with but one of the two substances, and less appreciably under the same circumstances at 68°. On the whole a temperature of 46° for a very long period of time acts rather unfavorably on Chelonus adults, and the other extreme of 77° is not conducive, in all cases, to prolongation of life. Room temperature which, at the time, fluctuated around 68° was very favorable to the parasites when they were given nourishment.

EFFECT OF PARASITE ON HOST

Pyrausta eggs parasitized by Chelonus hatch normally with those of the same mass which have not received any eggs of the parasite, and both parasitized and unparasitized larvae seem to develop at approximately the same rate until about the time they have reached the fourth instar. At this point the host larvae containing parasites are somewhat lighter in color (pale yellowish), smaller in size, (averaging 6 millimeters less in length and 1 millimeter less in width), and in general less robust than normal larvae of the same instar.

If the host larvae are of the first or summer generation, or are being reared under controlled laboratory conditions, those which are unparasitized continue their development into the fifth or last instar and pupate normally. On the other hand, those host larvae of the same generation which contain Chelonus are so retarded in growth that the parasites issue before the corn borers have entered the last stage.

In the case of the second or fall generation of host and parasite, the unparasitized larvae of Pyrausta molt to the fifth instar, but the borers infested by Chelonus remain in the fourth and do not equal in size the normal host larvae. These small parasitized larvae hibernate, and during the winter months it is easy to separate them, on the basis of size alone, from the normal overwintering borers. The results obtained from the separation of 87 "small" larvae out of a total of 1,166 overwintering host larvae from the field are given in Table 14. A total of 69 (or 79.3 per cent) of these isolated "small" larvae proved to be parasitized by Chelonus.

This possibility of isolating the small borers which are parasitized by *C. annulipes* from the others has a certain practical value, as during the packing of the borers for shipment the Chelonus-bearing larvae can be segregated in several boxes and receive special attention.

The reason for the smaller size of Pyrausta larvae containing Chelonus is not known. Whatever the causative factor, it undoubtedly exerts its influence during the early first stage of the parasite. Other host larvae from the same region may be parasitized by either

the ichneumonid *Inareolata punctoria* Rom. or the tachinid *Masicera senilis* Meig., but the presence of these parasites, except in rare instances, does not affect the size of the host larvae in any such way as does Chelonus.

TABLE 14.—*Isolation, on the basis of size, of Pyrausta nubilalis larvae parasitized by Chelonus annulipes in 1930*

Date	Lot No.	Total host larvae	Small host larvae isolated	Small host larvae from which Chelonus annulipes issued	Normal host larvae left	Normal host larvae from which Chelonus annulipes issued	Parasitism
		Number	*Number*	*Number*	*Number*	*Number*	*Per cent*
Feb. 27	1	306	28	25	278	1	8.5
Do	2	268	19	13	249	2	5.6
May 5	3	312	20	15	292	0	4.8
May 16	4	280	20	16	260	0	5.7
Total [1]		1,166	87	69	1,079	3	6.2
Percentage of total			7.5	79.3	92.5	0.3	

[1] Of the total number of Chelonus secured from these 4 lots, 95.8 per cent issued from the isolated small larvae and 4.2 per cent from the normal larvae left in the main lot.

The general activity of a Pyrausta larva parasitized by Chelonus, even for a short time after it has reached its maximum growth as a small larva, does not appear to differ from that of the normal unparasitized host. This may be due to the fact that until that time the parasite larva has been in its first stage. Growth has been rather slow, and the feeding of the parasite larva has probably not been sufficient to noticeably weaken the host. The increased consumption of food by the larger and faster growing second-stage and third-stage Chelonus larvae reduces the vitality of the host, however, and during the later part of the parasite's internal existence the host larva moves about sluggishly. It then incloses itself within a light cocoon as if preparing for pupation. Within this cocoon the host larva appears rather plump, the body lies motionless and curved somewhat dorsoventrally, and it has much the appearance of the prepupal state. In about 24 hours after such a condition has been reached the parasite larva issues and begins its external feeding.

The host larva, immediately after the Chelonus has issued and even before external feeding has commenced, is to all appearances in a lifeless state, and its body is shrunken and flabby. This is true in spite of the fact that the parasite larva has not yet devoured any of the vital organs of the borer.

The result of the external feeding of the parasite larva is the consumption of the entire contents of the host's body until nothing remains but the cuticle and the chitinized head parts.

FORCED ISSUANCE OF PARASITE LARVA FROM HOST

The method of supplying contact moisture to the overwintering host larvae by frequent soakings in order to force pupation has an equally favorable effect upon the late first-stage larvae of Chelonus within the borers in causing them to renew development and issue.

In Table 15 are shown the effects of soaking of the host larvae upon issuance of the parasite larvae at temperatures of 68° and 77° F. At the former temperature, between May 16 and June 14, it required an average of 24.6 days to get the parasite larvae to issue from the host, the minimum period being 22 days. At 77° F. between February 25 and March 26, an average of 17.6 days was necessary to cause the last-stage parasite larvae to issue. One Chelonus issued in a minimum of six days. At the same temperature, but later in the spring, between May 5 and 30, Chelonus larvae whose hosts were subjected to contact moisture issued in an average of 12.8 days. This shorter period among host larvae exposed to moisture later in the season coincides with the fact that it is generally easiest to break up the hibernation of borers which have been a long time in a dormant state.

TABLE 15.—*Time required for larvae of Chelonus annulipes to complete development within and issue from overwintering larvae of Pyrausta nubilalis when the latter are isolated, supplied with contact moisture, and kept at constant temperatures of 68° and 77° F., 1930*

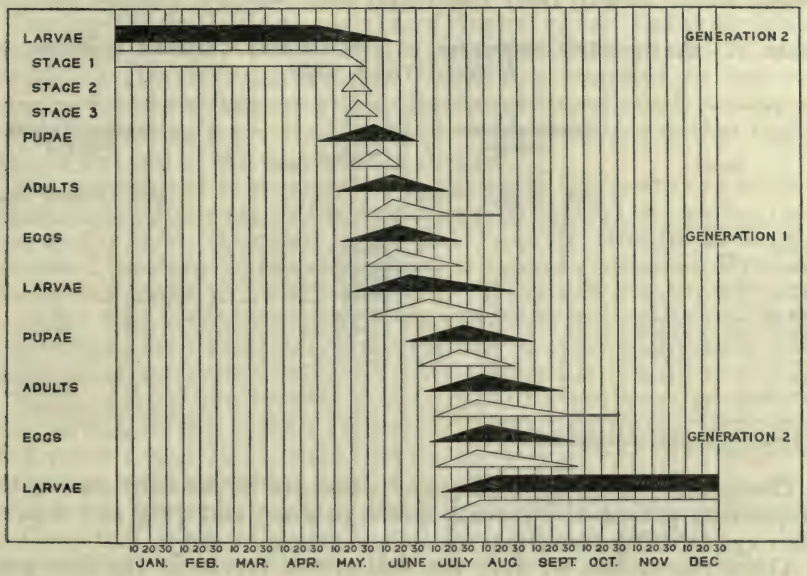
Length of time after isolation and soaking	Chelonus larvae issuing from host larvae			Length of time after isolation and soaking	Chelonus larvae issuing from host larvae		
	At 68° F.	At 77° F.			At 68° F.	At 77° F.	
	May 16 to June 14	Feb. 25 to Mar. 26	May 5 to 30		May 16 to June 14	Feb. 25 to Mar. 26	May 5 to 30
	Number	*Number*	*Number*		*Number*	*Number*	*Number*
6 days		1		21 days		2	
7 days				22 days	3	3	
8 days			1	23 days		1	
9 days		1	3	24 days		1	
10 days			3	25 days	2	1	1
11 days		3	6	26 days			
12 days		1	1	27 days	1		
13 days			3	28 days			
14 days			2	29 days	1		
15 days		2	1	30 days		1	
16 days		5					
17 days		5	1	Total	7	34	24
18 days		3					
19 days				Average number of days	24.6	17.6	12.8
20 days		4	2				

SEASONAL HISTORY

In the Italian regions under consideration *Chelonus annulipes*, like its host, passes through two full generations annually. (Fig. 12.) After a hibernation period lasting approximately from the middle of September until early May, spent as a late first-stage larva within the body cavity of the host, development is resumed, and from the middle to latter part of May the last-stage Chelonus larva issues, feeds externally upon the host, and spins its cocoon.

Data on the development of 97 individuals of the overwintering second generation of *C. annulipes* in the spring of 1930 are presented in Table 16. According to these observations the first larva of the second stage appeared on May 15, the first last-stage larva on May 17, the first pupa (or cocoon) on May 27, and the first empty cocoon on May 29. During a part of the period from May 1 to June 12,

Chelonus parasites in all three larval stages and as pupae were found in the field. From May 27 to May 31 this was especially true. Spring pupation of the host, amounting to 2.3 per cent on May 1, reached 70.4 per cent at the end of the month.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STAGE 1
STAGE 2
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PUPAE
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FIGURE 12.—Approximate relation between the seasonal history of *Chelonus annulipes* and its host *Pyrausta nubilalis*, determined from a study of all available data. Dark areas represent the stages in the development of the host and clear ones stages in the development of the parasite

TABLE 16.—*Spring development of 97 overwintering Chelonus annulipes, and comparison with host pupation at St. Giorgio di Nogaro, Italy, 1930* [1]

Date	Total individuals	Condition of Chelonus annulipes						Pupation of host
		Late first-stage larva	Second-stage larva	Last-stage larva	Early pupa	Late pupa	Empty cocoon	
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Per cent*
May 1	2	2						2.3
May 15	3	2	1					3.5
May 17	1			1				
May 18	2		2					7.6
May 22	1		1					10.8
May 27	25	8	5	2	8	2		25.9
May 28	15	3	6	1	2	3		27.3
May 29	8		2		4	1	1	35.4
May 30	12	1	1	7	2	1		42.9
May 31	8	1	1	1	3	2		70.4
June 2	5			2	2	1		
June 3	3				3			80.2
June 11	3				2	1		
June 12	9					8	1	

[1] Data taken on material collected from old cornstalks in the field.

Adult emergence begins the last of May, and continues into the third week of June, as indicated by a study of 32 individuals which were collected as cocoons in the field at St. Giorgio di Nogaro in

the spring of 1930 and from which the adults were reared under outdoor insectary conditions at Hyères, France. Table 17 shows the emergence obtained at Hyères. There seemed to be no marked difference in the time of emergence of the two sexes. The first empty cocoon in the field in Italy was found May 29.

TABLE 17.—*Spring adult emergence of overwintered Chelonus annulipes, at Hyères, France, 1930*

Date	Number of adults emerged			Date	Number of adults emerged		
	Male	Female	Total		Male	Female	Total
June 6	3	1	4	June 16	1	-------	1
June 7	1	-------	1	June 17	-------	2	2
June 8	-------	1	1	June 18	-------	-------	-------
June 9	1	1	2	June 19	-------	-------	-------
June 10	-------	1	1	June 20	1	1	[1] 3
June 11	-------	2	2	June 21	1	1	2
June 12	1	1	[1] 3	June 22	-------	-------	-------
June 13	1	1	2	June 23	2	-------	2
June 14	2	3	5				
June 15	1	-------	1	Total	15	15	32

[1] Includes 1 adult of undetermined sex.

The adults emerging in May and June are in the field during the oviposition period of Pyrausta moths in June and July and deposit their eggs during this time.

About the middle of July the full-grown larvae of the first generation of Chelonus issue from fourth-instar hosts and spin their cocoons within the tunnels of the borer. The maximum issuance of the Chelonus larvae and subsequent spinning cover a period of about a week, and by July 25 most of the parasites are in their cocoons. On July 29, 1926, a full cocoon was found at Piacenza, Italy, and from July 22 to 24, 1929, fresh cocoons were common in the fields around St. Giorgio di Nogaro.

In 1929 near St. Giorgio di Nogaro adult emergence of the first generation of the parasite was first recorded on July 24. On the following day 3.3 per cent of the cocoons collected in the field were found to be empty. A summary of the data upon early emergence for that summer is given in Table 18.

TABLE 18.—*Early adult emergence of first-generation Chelonus annulipes at St. Giorgio di Nogaro, Italy, 1929*

Date	Cocoons collected		Emergence	Pupation of host
	Full	Empty		
	Number	*Number*	*Per cent*	*Per cent*
July 22	101	----------	----------	24.8
July 23	146	----------	----------	25.0
July 24	194	----------	[1]	23.9
July 25	204	7	3.3	37.5
July 26	576	15	2.5	24.0
July 27	417	21	4.8	67.6
July 29	361	10	2.7	51.9

[1] First record.

Further data upon emergence in this area were not taken, but it was evident, from the fact that the greater part of the cocoons collected in late July contained advanced pupae, that many adults would soon be in the field. It is therefore safe to say that during the first week of August the emergence of Chelonus reached its peak.

During the period August 1 to 9, inclusive, an assistant taking survey data in the "pump lands" around Piove di Sacco collected a total of 115 Chelonus cocoons. With the exception of two full cocoons found on August 2 and four others on August 5, all were empty, indicating a practically 100 per cent emergence in that region also, by the end of the first week in August.

The progress of host pupation as shown in the preceding table is evidence that Pyrausta moths would soon be out and depositing their eggs in the field. Further, in one field near St. Giorgio di Nogaro examined on July 27 the emergence of second-generation Pyrausta moths was found to be 31.4 per cent. While the number of moths in flight was perhaps somewhat less in several neighboring fields, it is certain that a considerable quantity of borer egg masses were available at the time Chelonus adults became abundant.

The longevity of Chelonus females would presuppose an oviposition period, in this second generation, extending to the time when all Pyrausta eggs in the field had hatched, or during the remainder of August and the greater part of September.

Chelonus larvae hatching in the fall pass through the earlier part of their first stage of growth, and then enter a condition of rest synchronous with the dormant period of the Pyrausta host larvae.

HYPERPARASITES

Chelonus annulipes itself suffers from the attack of other insect parasites. In one lot of 232 cocoons collected in Italy in 1929 the total hyperparasitism was 8.8 per cent, and in a collection of 1,432 Chelonus cocoons received from Italy the same year, D. W. Jones, of the Arlington, Mass., laboratory, found that 2.1 per cent produced hyperparasites.

Six specimens of *Exeristes roborator* Grav., all small in size, one colony of chalcids determined as *Eupteromalus* sp., and several adults of another chalcid, *Hypopteromalus poecilopus* Cwfd., have been reared from cocoons of *Chelonus annulipes*.

METHODS OF COLLECTION AND SHIPMENT

During the latter week of July, 1929, cocoons of *C. annulipes*, most of which were freshly spun, were collected in the cornfields near St. Giorgio di Nogaro, Italy. The worker, provided with a cardboard box and a knife, examined two rows of corn at a time, observing the tassel and upper stem of each plant. Every tassel infested with *P. nubilalis* was carefully cut open and examined. If a Chelonus cocoon was found within the borer tunnel the corn stem was at once cut at a distance of about one-half inch on each side of the cocoon, and the green piece containing the cocoon put in the collecting box. Practically all of the cocoons were found in the tassels, and a maximum of six was at one time removed from a single tassel. Possibly parasitism was equally distributed among Pyrausta

occurring in other parts of the plant; it was not possible to procure data on this point. Later all the material so collected was examined by the writer and each parasite cocoon carefully removed from its position in the tunnel of the plant. The free cocoons were then placed in an ice box and kept until the end of the collecting season.

For shipment the cocoons were packed in small cardboard boxes, 50 to a box, and put within a large wooden box, which was transported in cold storage direct to the shipping point and dispatched to the United States Entomological Laboratory, Arlington, Mass.,[6] by the first ship. During the trans-Atlantic passage the shipment remained in cold storage.

The collection of Chelonus of the second or overwintering generation in the same year consisted in gathering the host larvae within which the parasite passes the winter months. This was accomplished by the usual method of collecting Pyrausta larvae. A considerable number of workers were hired to cut the cornstalks brought from a field to a central station. All Pyrausta larvae and their parasites were saved for shipment. Those larvae parasitized by Chelonus, although smaller than the normal, were included with others which were put into round screened tin cans containing narrow strips of corrugated paper, into the holes of which the borers crawled, sealing them with thin silken webs. Such cans with about 400 host larvae so incased were packed in strong wooden boxes and shipped in cold storage to the Arlington laboratory. In future collections of the overwintering borers all of the small larvae parasitized by *C. annulipes* will be isolated in certain cans and given special attention.

SUMMARY

The braconid *Chelonus annulipes* Wesm., first discovered as a parasite of the European corn borer, *Pyrausta nubilalis*, in corn at Piacenza, Italy, in 1925, has since been found to be of economic importance over a somewhat restricted area near St. Giorgio di Nogaro and in the environs of Piove di Sacco, Italy. Parasitism of the first generation of Pyrausta in 1929 at the former point averaged 16.9 and at the latter 8 per cent, with a maximum of 28.6 per cent in one cornfield at St. Giorgio di Nogaro. Pyrausta of the second generation that year was much less parasitized; at St. Giorgio di Nogaro the average was only 3.5 per cent. The species, as a parasite of the borer, appears to occur over most of northern Italy.

The adult of this species, determined by C. Ferriere of the British Museum, does not have the more or less typically wasplike appearance of the other known hymenopterous parasites of the European corn borer. It is a black, robust insect with smoky colored wings and an abdomen protected by a single, hard, dorsally convex sclerite. The newly deposited egg is white, smooth, cylindrical, and arcuate. The first-stage larva is characterized by a pair of pointed, curved, chitinous mandibles, a considerable number of dorsal spines, and a partly evaginated anal vesicle. In the second stage the body appears smooth, the mandibles are lightly chitinized

[6] From D. W. Jones, of the Arlington laboratory, it was learned that out of 1,432 cocoons of Chelonus received by him only 11 adults had emerged en route, and but 2 of this number were dead on arrival. From this shipment an emergence of 62.9 per cent was obtained.

and indistinct, and the anal vesicle is prominent. Open spiracles appear on the second thoracic and first six abdominal segments of the last-stage larva, and dorsally, on each of the abdominal segments 2 to 6, are grouped two sets of long brown spines. The mandibles of this stage are brown, well chitinized, and many toothed, and the head in addition possesses a number of characteristic spines and sensory organs. Within a glistening papery white cocoon the pupa, pale yellow for a few days, darkens to the black of the adult.

In general, the internal anatomy of the larva differs little from that of other braconids. In the last-stage larva, however, the arrangement of the integumentary muscles is not complex, and the fibers are not grouped into bundles, the silk glands are not greatly convoluted, and the Malpighian tubes are absent.

The female of *C. annulipes* deposits her egg in that of the host, and the larva passes through three stages within the growing borer. During its last stage the parasite larva issues from the fourth-instar Pyrausta, devours all remaining contents of the latter, spins a cocoon, and pupates.

At a constant temperature of 77° F., 2 days are required for the incubation of the egg of Chelonus; about 20 days are needed for the total larval growth; and pupation, at that temperature, takes an average of 9½ days. Higher or lower temperatures shorten or lengthen development of the parasite in all stages, and under field conditions it is probable that the egg-to-adult period covers about 40 days.

C. annulipes is easily reared in the laboratory. The female, whether mated or not, will usually start oviposition soon after emergence. Unmated females will reproduce parthenogenetically, the resulting progeny in all known cases being males. Both male and female adults, when given food and water and kept at various temperatures between 46° and 77° F., will live for some time. One nourished female at a fluctuating room temperature lived 84 days (a maximum life period for the species), and a similarly nourished male at a constant temperature of 68° lived 69 days.

In northern Italy *C. annulipes*, like its host, has two generations annually. It overwinters as a late first-stage larva within the fourth-instar borer and in early May resumes development. Pupation and emergence follow toward the middle and end of the month, and in early June a considerable number of adults are in the field to attack the eggs of the first host generation already present on young corn plants. The last-stage Chelonus larvae from this lot issue and spin their cocoons in the middle of July, and during the last week of that month and the early part of August the adults emerge and begin ovipositing in the Pyrausta eggs of the second generation. Both host and parasite of this generation, after a certain amount of growth, enter a dormant condition for the winter months.

The first importation of this parasite into the United States was made in the summer of 1929, and during 1929 and 1930 a total of 10,767 individuals were shipped from Italy. Chelonus are more easily procured during the winter months, when they occur as dormant late first-stage larvae within the hibernating host larvae. The adults are collected as they emerge the next spring.

LITERATURE CITED

(1) DALLA TORRE, C. G. DE
1898. CATALOGUS HYMENOPTERORUM HUCUSQUE DESCRIPTORUM SYSTEMATICUS ET SYNONYMICUS. V. 4: BRACONIDAE. 323 p. Lipsiae.

(2) GAULLE, J. DE
1908. CATALOGUE SYSTÉMATIQUE & BIOLOGIQUE DES HYMÉNOPTÈRES DE FRANCE. 171 p. Paris.

(3) GENIEYS, P.
1925. HABROBRACON BREVICORNIS WESM. Ann. Ent. Soc. Amer. 18: 143–202, illus.

(4) LUGINBILL, P.
1928. THE FALL ARMY WORM. U. S. Dept. Agr. Tech. Bul. 34, 92 p., illus.

(5) MARSHALL, T. A.
1888. LES BRACONIDES. 603 p., illus. *In* Andre, E., Species des Hyménoptères d'Europe et d'Algérie. v. 4.

(6) PARKER, H. L.
1931. MACROCENTRUS GIFUENSIS ASHMEAD, A POLYEMBRYONIC BRACONID PARASITE IN THE EUROPEAN CORN BORER. U. S. Dept. Agr. Tech. Bul. 230, 63 p., illus.

(7) ———
1931. NOTES ON METEORUS (ZEMIOTES) NIGRICOLLIS THOMSON, AN OCCASIONAL PARASITE OF THE EUROPEAN CORN BORER. Ent. Soc. Wash. Proc. 33 (5): [93]–103, illus.

(8) ——— VANCE, A. M., SMITH, H. D., and GAMKRELIDZE, W.
1929. PYRAUSTA NUBILALIS HÜBN. IN EUROPE: NOTES ON INFESTATION AND PARASITISM FROM 1926 TO 1928. Jour. Econ. Ent. 22: 688–693.

(9) PIERCE, W. D., and HOLLOWAY, T. E.
1912. NOTES ON THE BIOLOGY OF CHELONUS TEXANUS CRESS. Jour. Econ. Ent. 5: [425]–428.

(10) SILVESTRI, F.
1908. LA TIGNOLA DELL'OLIVO (PRAYS OLEELLUS FABR.) Boll. Lab. Zool. Gen. e Agr. R. Scuola Super. Agr. Portici 2: [83]–184, illus.

(11) SZÉPLIGETI, V.
1896. BEITRÄGE ZUR KENNTNISS DER UNGARISCHEN BRACONIDEN. Természetrajzi Füzetek 19: 228–242.

(12) THOMPSON, W. R., and PARKER, H. L.
1928. THE EUROPEAN CORN BORER AND ITS CONTROLLING FACTORS IN EUROPE. U. S. Dept. Agr. Tech. Bul. 59, 63 p., illus.

(13) THOMSON, C. G.
1874. OPUSCULA ENTOMOLOGICA. Fasc. VI, p. 535–612. Lund.

(14) VANCE, A. M.
1931. APANTELES THOMPSONI LYLE, A BRACONID PARASITE OF THE EUROPEAN CORN BORER. U. S. Dept. Agr. Tech. Bul. 233, 28 p., illus.

(15) VAN ZWALUWENBURG, R. H.
1926. INSECT ENEMIES OF SUGARCANE IN WESTERN MEXICO. Jour. Econ. Ent. 19: 664–669.

(16) VICKERY, R. A.
1929. STUDIES ON THE FALL ARMY WORM IN THE GULF COAST DISTRICT OF TEXAS. U. S. Dept. Agr. Tech. Bul. 138, 64 p.

(17) WILLARD, H. F.
1927. PARASITES OF THE PINK BOLLWORM IN HAWAII. U. S. Dept. Agr. Tech. Bul. 19, 16 p., illus.

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FACTORS AFFECTING THE DEVELOPMENT OF LOOSE SMUT IN BARLEY AND ITS CONTROL BY DUST FUNGICIDES

By R. W. LEUKEL

Associate Pathologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry

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INTRODUCTION

In the past loose smut in barley, caused by *Ustilago nuda* (Jens.) Kell. and Sw., generally speaking, has been considered amenable to control only by the hot-water treatment. In some barley varieties it has been controlled, or the percentage of infection greatly reduced, at times by the use of formaldehyde or various organic mercury solutions. In 1914, Johnson (*5*)[1] reported that a 0.3 per cent solution of 40 per cent formaldehyde (1:320) had reduced loose smut in barley to a slight trace.[2] In 1918 Humphrey and Potter (*4*) intimated that barley loose smut could be controlled or its occurrence reduced by the use of formaldehyde. Tisdale et al. (*18*) reported in 1923 that formaldehyde was as effective as hot water in the control of loose smut in six varieties of winter barley. In 1925 Tisdale et al. (*19*) reported that satisfactory control of loose smut in Wisconsin Winter, Orel, and Tennessee Winter barleys had followed the use of organic mercury solutions. Rodenhiser and Stakman (*14*) reported in 1925 that they had reduced loose smut of barley from 7 per cent to a trace by the use of organic mercury solutions at 45° C. In 1926 Conners (*1*) reported that organic mercury solutions at ordinary temperatures failed to control loose smut in Junior (hull-less) barley and only partly controlled it at 45° C., but that the modified hot-water treatment eliminated it. Kirby (*6, p. 50–53*) stated in 1927 that soaking the seed in formaldehyde or organic mercury solutions controlled loose smut in 6-row

[1] Italic numbers in parentheses refer to Literature Cited, p. 18.
[2] This was in Oderbrucker barley Wisconsin Pedigree No. 9. The controls contained 5 to 6 per cent of loose smut.

winter barley and reduced its occurrence in certain 6-row spring varieties.

In 1929, Howitt and Stone [3] reduced the percentage of loose smut in O. A. C. No. 21 barley from 10 per cent to 4, 2, and 1 per cent with solutions of formaldehyde, Semesan, and Uspulun, respectively.

These few citations indicate that loose smut of barley generally has been found more difficult to control than any other cereal smut except loose smut of wheat. Dust fungicides have not been considered effective for the control of this disease and up to the present time seldom have been used for this purpose.

In the fall of 1926 field experiments were started at the Arlington Experiment Farm, Rosslyn, Va., to test the efficacy of certain fungicidal dusts in the control of covered smut and stripe disease in Tennessee Winter barley. It was observed, during the first year of these experiments, that these dusts also reduced considerably the incidence of loose smut, which occurred to a slight degree in this variety. Therefore, data were taken on the control of this disease in this variety of barley, and further seed-treatment experiments with this and other varieties were later conducted in order to investigate the possibilities of controlling loose smut, as well as other diseases of barley, by means of dust fungicides.

METHODS AND MATERIALS

The general procedure followed by the writer in seed-treatment experiments with barley has been described in a previous paper (*9*). The dusts were usually applied at the rate of 3 or 4 ounces per bushel, and the seed was thoroughly mixed with the dusts until every kernel was completely coated. Then the seed was shaken for a moment in a fine sieve to remove any excess dust. It was sown in rod rows usually replicated a number of times for each treatment. Smut data were secured by counting all the heads of loose smut as well as the total heads in every row in order to determine the percentage of infection.

Twenty-seven dusts and two liquid disinfectants were used [4] in the course of these experiments. The names of the dust fungicides used and of the manufacturers are listed below.

Abavit B, Chemische Fabrik Ludwig Meyer, Mainz, Germany.

Tutan, S. F. A. No. 225 and No. 225–V, Saccharin-Fabrik Aktiengesellschaft, Magdeburg, Germany.

Höchst (also called "Trockenbeize Tillantin"), J. G. Farbenindustrie Aktiengesellschaft, Höchst a. M., Germany.

Vitrioline, Usines Schloesing Frères et Cie., Marseille, France.

Mercury C and Sterocide, Roessler & Hasslacher Chemical Co., Perth Amboy, N. J.

Corona 80–B and Corona Oat Dust, Corona Chemical Division of the Pittsburgh Plate Glass Co., Milwaukee, Wis.

Bayer Dust, the Bayer Co., New York.

Wa Wa Dust, the Chicago Process Co., Chicago, Ill.[5]

Smuttox, the Stadler Products Co., Cleveland, Ohio.

Sanoseed Grain Dust, Ansbacher Siegle Corporation, New York.

Acco Dust No. 7, American Cyanamid Co., New York.

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[3] Unpublished data.

[4] The dusts used in these experiments were the only ones submitted to the author for experimental purposes. Their use in these experiments does not imply that any other dusts on the market at that time might not have proved efficacious under similar circumstances. The names of the manufacturers are furnished merely as information, and mention of them does not imply any recommendation of the firms or their products.

[5] Now located at Newark, N. J.

Semesan, Semesan Jr., Dupont Nos. 12, 35, 45, 53, and 64, E. I. du Pont de Nemours & Co., Wilmington, Del.

Ceresan, Dubay P. M. A., and Dubay 655 and 665, the Bayer Semesan Co., New York.

Wienert's Compound, F. Wienert, Lock Haven, Pa.

The liquid fungicides used were Germisan (made by the manufacturers of Tutan) and ordinary formaldehyde solution.

The following varieties of barley were used:

Tennessee Winter 52, C. I.[6] No. 3543.
Wisconsin Winter, C. I. No. 2159.
Wisconsin Pedigree 6, C. I. No. 1146.
Wisconsin Pedigree 5, C. I. No. 4666.
Minnesota Velvet, C. I. No. 4252.

Three lots of unknown varieties were secured from different farms in Wisconsin.

EXPERIMENTS IN 1926–27

During the 1926–27 season, in one series of six treatments replicated 48 times and with 2.5 per cent of loose smut in the controls, Wa Wa Dust and Abavit B reduced the disease to 0.01 and 0.02 per cent, respectively, while the other four dusts reduced it to less than 0.5 per cent. (Table 1.)

TABLE 1.—*Loose smut in Tennessee Winter barley grown from untreated seed and from seed treated with dust fungicides and sown in rod rows, 1926–27*

[Series 1, 48 replications, sown Oct. 12, in soil 45 per cent saturated; series 2, 24 replications, sown Oct. 16, in soil 65 per cent saturated]

Seed-treatment compound		Heads of loose smut in—			
No.	Name	Series 1		Series 2	
		Number	*Per cent*	*Number*	*Per cent*
	Control	565	2.5	243	1.01
1	Abavit B	5	.02	0	0
2	S. F. A. No. 225–V	29	.10	0	0
3	Bayer Dust	62	.20	8	.03
4	Semesan	15	.05	0	0
5	Dupont No. 12	10	.04	0	0
6	Wa Wa Dust	4	.01	0	0

In another series of six treatments, replicated 24 times in rod rows, in which the controls showed 1 per cent loose smut (Table 1), five of the dusts eliminated the disease, while the other dust reduced it to 0.03 per cent. These results were not considered very significant on account of the low percentages of loose smut appearing in the controls.

EXPERIMENTS IN 1927–28

During the 1927–28 season 14 dusts were used in seed-treatment experiments for the control of loose and covered smuts and stripe disease in Tennessee Winter barley. Two parallel series were sown. Series 1 was sown on September 21 in relatively dry soil and series 2 on October 7 in relatively wet soil. The mean soil temperature

[6] Accession number of the Division of Cereal Crops and Diseases.

from sowing to emergence in both series was about 16° C. Very little loose smut developed in the controls in either series. (Table 2.)

TABLE 2.—*Effect of seed treatment with dust fungicides on the incidence of loose smut in Tennessee Winter barley grown in field plots, 1927–28*

[Series 1 sown Sept. 21 and grown to emergence in relatively dry soil; series 2 sown Oct. 7 and grown to emergence in relatively wet soil]

Seed-treatment compound		Heads of loose smut in—			
No.	Name	Series 1		Series 2	
		Number	*Per cent*	*Number*	*Per cent*
	Control	101	0.73	41	0.35
1	Abavit B	8	.06	0	0
2	S. F. A. No. 225	11	.08	7	.05
3	S. F. A. No. 225–V	58	.41	10	.07
4	Höchst	9	.06	3	.02
5	Tutan	59	.39	5	.04
6	Vitrioline	90	.61	15	.12
7	Mercury "C"	25	.17	8	.06
	Control	109	.68	45	.38
8	Wa Wa Dust	3	.02	0	0
9	Semesan	32	.21	3	.02
10	Semesan Jr	45	.30	1	.01
11	Dupont 35	70	.48	1	.01
12	Dupont 45	38	.26	9	.07
13	Dupont 53	60	.40	16	.13
14	Dupont 64	37	.26	10	.08

In series 1 with an average of 0.7 per cent loose smut in the controls, Abavit B, Höchst, and Wa Wa Dust reduced it the most, while in series 2 with an average of only 0.36 per cent loose smut in the controls, Abavit B and Wa Wa Dust eliminated it. These results, like those of the previous season, were not considered very significant, because of the light infection in the controls.

EXPERIMENTS IN 1928–29

During the 1928–29 season Tennessee Winter and Wisconsin Winter barleys were used in experiments on the control of barley smuts. The seed was treated with the different fungicides and, along with untreated controls, was sown in replicated rod rows in three series. Series 1, containing 20 replications, was sown September 29. This yielded no data because of total winterkilling. Series 2, containing four replications, and series 3, containing eight replications, were sown October 5 and October 18, respectively. The soil temperature and rainfall records for the periods of emergence in these two series are shown in Table 3, and the infection data taken May 6, 1929, are shown in Table 4.

TABLE 3.—*Soil temperature and rainfall records from dates of sowing seed to dates seedlings emerged, in experiments on the control of loose smut in Tennessee Winter and Wisconsin Winter barleys sown in rod rows, 1928–29*

[Series 1, 20 replications, sown Sept. 29 (winterkilled); series 2, 4 replications, sown Oct. 5, in soil 41 per cent saturated; series 3, 8 replications, sown Oct. 18, in soil 19 per cent saturated at sowing and 25 per cent two days later]

Days after sowing	Series 2				Series 3			
	Soil temperature			Rainfall	Soil temperature			Rainfall
	Maximum	Minimum	Mean		Maximum	Minimum	Mean	
	° *C.*	° *C.*	° *C.*	*Inch*	° *C.*	° *C.*	° *C.*	*Inch*
1	23	13	16.8	0	24	17	18.7	0.13
2	21	9	14.3	0.11	18	8	13.5	
3	21	8	13.7	0	20	5	11.0	
4	24	12	17.0	0	20	6	12.4	
5	23	12	16.5	0	19	13	15.2	
6	23	9	15.3	0	17	6	10.8	.11
7					15	3	8.1	
8					15	2	7.0	
9					11	0	5.2	
10					15	5	9.5	
Average or total	22.5	10.5	[1] 16.1	.11	17.4	6.5	11.1	.24

[1] Not the average of figures above, but of 2-hourly temperatures for whole period.

TABLE 4.—*Loose smut in Tennessee Winter and Wisconsin Winter barleys grown from untreated seed and from seed treated with different fungicides and sown in rod rows, 1928–29*

Series 1, 20 replications, sown Sept. 29 (winterkilled); series 2, 4 replications, sown Oct. 5; series 3, 8 replications, sown Oct. 18]

Seed-treatment compound		Heads of loose smut in—							
		Tennessee Winter				Wisconsin Winter			
No.	Name	Series 2		Series 3		Series 2		Series 3	
		Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
	Control	38	2.5	209	4.5	55	4.6	194	4.7
1	Ceresan	0	0	38	.9	5	.3	61	1.4
2	Dubay P. M. A	0	0	19	.5	0	0	23	.5
3	Höchst	0	0	32	.7	1	.1	88	1.8
4	Abavit B	0	0	72	1.8	4	.3	154	3.6
5	Formaldehyde [1]	1	.2	0	0	4	.3	29	.7

[1] Treatment: Water 15 minutes, drained and covered 4 hours, 1:320 formaldehyde solution 20 minutes, drained and covered 3 hours, dried overnight.

In series 2, in which the soil was 41 per cent saturated at the time of sowing, control of loose smut in both barley varieties was better than in series 3, in which the soil was 19 per cent saturated at the time of sowing and was relatively dry during the entire period of emergence.

In the spring of 1929, seven dusts and one liquid fungicide were used in limited field experiments for the control of loose smut in barley grown from the same lot of Wisconsin Pedigree No. 5 seed used in a greenhouse experiment described later. (Table 7.) The seed was dusted at the rate of 4 ounces per bushel and sown in two series. Series 1 was sown March 13 in soil of low fertility, and the

plants emerged March 24. Series 2 was sown April 6 in rich soil, and emergence took place April 14. The soil temperature and rainfall records for both series are shown in Table 5.

TABLE 5.—*Soil temperature and rainfall records from dates of sowing seed to dates seedlings emerged, in field experiments on the control of loose smut in Wisconsin Pedigree No. 5 barley, 1929*

[Series 1, sown in poor soil Mar. 13, emerged Mar. 24; series 2, sown in rich soil Apr. 6, emerged Apr. 14]

Days after sowing	Series 1				Series 2			
	Soil temperature			Rainfall	Soil temperature			Rainfall
	Maximum	Minimum	Mean		Maximum	Minimum	Mean	
	° C.	° C.	° C.	Inch	° C.	° C.	° C.	Inch
1	12	11	11.4	0.13	25	19	22.2	
2	15	11	13.0		28	14	20.4	
3	15	11	12.6	.02	27	15	20.8	
4	14	8	11.8	.05	27	17	20.8	
5	12	4	7.7		16	8	13.5	0.79
6	16	2	7.3		7	5	6.4	.03
7	14	3	7.0		22	5	12.0	.39
8	16	5	10.1		20	6	12.5	
9	19	4	10.6					
10	19	11	14.7	.09				
11	18	14	15.7	.15				
Average	15.4	7.6	11.1		21.5	11.1	16.1	

The soil in series 1 was 40 per cent saturated at the time of sowing, and 0.44 of an inch of rain fell before the plants emerged. The average soil temperature during this period was 11.1° C. Therefore, the seed germinated and the seedlings grew to emergence in a relatively cold dry soil. The smut data, which were taken June 9, are shown in Table 6.

TABLE 6.—*Loose smut in Wisconsin Pedigree No. 5 barley grown from untreated seed and from seed treated with different fungicides and sown in rod rows, 1929*

[Series 1, four replications in poor soil, sown Mar. 13; series 2, two replications in rich soil, sown Apr. 6]

Seed-treatment compound		Heads of loose smut in—			
No.	Name	Series 1		Series 2	
		Number	Per cent	Number	Per cent
	First control	21	3.0	9	1.8
1	Ceresan	0	0	0	0
2	Dubay P. M. A	1	.2	0	0
3	Höchst	0	0	0	0
4	Abavit B	0	0	0	0
	Second control	18	2.6	8	1.6
5	Mercury "C"	0	0	0	0
6	Corona 80-B	3	.4	0	0
7	Smuttox	2	.3	0	0
8	Germisan [1]	0	0	0	0

[1] 0.25 per cent solution for 1 hour.

Four of the dusts and the one liquid fungicide eliminated loose smut, while the rest of the dusts greatly reduced its occurrence in comparison with the controls from untreated seed, although the latter averaged only 2.8 per cent smut.

The soil in series 2 was about 75 per cent saturated at the time of sowing, and from sowing to emergence the rainfall amounted to about an inch. The mean soil temperature during this period was 16.1° C. In this series, therefore, the soil was warmer and much wetter during the period of emergence than the soil in series 1. No smut appeared in the rows from treated seed (Table 6), while the smut in the control rows averaged only 1.7 per cent. Evidently soil conditions in both series were highly unfavorable for loose-smut development, because in a subsequent greenhouse experiment 38.7 per cent of the plants from this same lot of seed were infected with loose smut. (Table 7.)

TABLE 7.—*Control of loose and covered smuts in Wisconsin Pedigree No. 5 barley grown from seed dusted with Ceresan and sown in the greenhouse January 5, 1929, along with untreated seed*

[Plants emerged Jan. 11, the final data being taken Apr. 6, 1929]

Row No.	Treated or untreated	Total plants	Total heads	Loose smut				Covered smut			
				Plants infected		Heads infected		Plants infected		Heads infected	
				Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
1	Untreated	17	56	6	35.3	23	41.1	6	35.3	13	23.2
2–6	Treated	93	221	0	0	0	0	0	0	0	0
7	Untreated	17	37	6	35.3	10	27.0	9	52.9	17	45.9
8–12	Treated	91	227	0	0	0	0	0	0	0	0
13	Untreated	20	34	6	30.0	6	17.6	13	65.0	19	55.9
14–18	Treated	93	223	0	0	0	0	0	0	0	0
19	Untreated	17	41	10	58.8	21	51.2	5	29.4	12	29.3
20–24	Treated	95	225	0	0	0	0	0	0	0	0
25	Untreated	20	41	6	30.0	16	39.0	8	40.0	8	19.5
26–30	Treated	95	234	0	0	0	0	0	0	0	0
31	Untreated	20	40	9	45.0	15	37.5	7	35.0	13	32.5
32–36	Treated	88	209	0	0	0	0	0	0	0	0
Totals: Untreated seed		111	249	43	38.7	91	36.5	48	43.2	82	33
Treated seed		555	1,339	0	0	0	0	0	0	0	0

During the winter of 1928–29 a seed-treatment experiment of rather limited scope was conducted in the greenhouse on the control of loose smut in heavily infected Oderbrucker (Wisconsin Pedigree No. 5) barley by the use of ethyl mercury chloride, a then relatively new dust which is now marketed under the trade name of Ceresan. Previously it had been found effective in the control of stripe disease in barley (*10*) and of bunt in wheat (*8*). Tisdale and Cannon (*17*) also had reported satisfactory results from its use in the control of loose smut in Tennessee Winter barley.

The greenhouse bench used was 40 feet long, 3½ feet wide, and 8 inches deep and was filled with rather rich compost soil. The seed was treated at the rate of 4 ounces of dust per bushel. It was sown 1½ inches deep in rows 6 inches apart at the rate of 20 seeds per row, every sixth row being an untreated control. The seed was treated and sown January 5, and the seedlings emerged January 11. The temperature during this time was between 20° and 25° C., and the soil was kept moderately moist. In order to hasten shooting and heading of the plants a 24-hour growing day was provided by the use of electric lights, beginning January 25. On April 6, when all the culms were fully headed, the plants were pulled carefully and plant and head counts were made. These results are shown in detail and also

summarized in Table 7. Both the loose and covered smuts were completely eliminated by Ceresan, while in the controls 38.7 and 43.2 per cent of the plants and 36.5 and 33 per cent of the heads were infected with loose and covered smuts, respectively.

EXPERIMENTS IN 1929–30

The following winter an experiment similar to the one described above but on a smaller scale was carried out with seed of two other varieties known to be infected with loose smut. The resultant data are shown in Table 8.

TABLE 8.—*Loose smut in two varieties of barley grown from untreated seed and from seed treated with Ceresan and sown in the greenhouse November 4, 1929*

[Final data taken Feb. 20, 1930]

Variety	Untreated seed			Treated seed		
	Total heads	Smutted heads		Total heads	Smutted heads	
		Number	*Per cent*		*Number*	*Per cent*
Wisconsin Pedigree No. 6	60	19	31.7	197	1	0.5
Unknown variety	50	3	6.0	204	3	1.5

In one variety, Wisconsin Pedigree No. 6, loose smut was reduced to 0.05 per cent, as compared with 31.7 per cent in the controls. In the other variety (name unknown) loose smut was reduced to 1.5 per cent, while 6 per cent occurred in the controls.

While these greenhouse results with two varieties were very gratifying, it must be borne in mind that, although the conditions for smut development must have been favorable, judging by the high percentage in the controls, the conditions for the maximum efficiency of the dust fungicide used also may have prevailed to a greater degree than usually occurs in the field.

In the spring of 1930 six lots of barley seed were used in seed-treatment experiments on the control of stripe disease and loose smut. Three of these seed lots, Wisconsin Pedigree No. 5 and No. 6 and an unnamed variety from Oconomowoc, Wis., had been used in previously described experiments. (Tables 7 and 8.) The three other seed lots were obtained from different localities in Wisconsin and were known to be infected with stripe disease and to some extent with loose smut.

Quantities of seed of all six varieties or lots were treated with different standard or experimental fungicides and sown in paired rod rows March 20, 1930. The soil was 40 per cent saturated both at the time of sowing and at the time when the seedlings emerged. During this period the rainfall amounted to an inch, and the mean soil temperature was 7.5° C. Loose-smut data, taken June 4, 1930, and shown in Table 9, are not very significant on account of the light infection in the controls.

TABLE 9.—*Loose smut in six varieties of spring barley grown from untreated seed and from seed treated with different fungicides and sown in paired rod rows, March 20, 1930*

Seed-treatment compound		Heads of loose smut in—											
No.	Name	Wisconsin Pedigree No. 5		Wisconsin Pedigree No. 6		Minnesota Velvet		Farmers' samples					
								No. 1		No. 2		No. 3	
		Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
	First control	0	0	3	0.5	4	0.7	19	2.4	2	0.3	0	0
1	Ceresan	0	0	0	0	3	.5	18	2.3	0	0	1	.1
2	Dubay 655	0	0	0	0	1	.2	7	.9	0	0	0	0
3	Dubay 665	0	0	0	0	2	.3	18	2.3	1	.1	0	0
4	Abavit B	0	0	0	0	4	.7	16	2.0	5	.8	2	.2
	Second control	1	.1	2	.3	3	.4	20	2.5	1	.2	2	.2
5	Höchst	0	0	2	.3	2	.3	17	2.1	1	.2	1	.1
6	Wa Wa Dust	0	0	1	.2	2	.3	11	1.4	1	.2	2	.2
7	Corona Oat Dust	0	0	1	.2	1	.2	20	2.5	0	0	2	.2
8	Sterocide	0	0	1	.2	0	0	23	2.9	0	0	2	.2
	Third control	0	0	0	0	0	0	22	2.9	0	0	3	.4
9	Sanoseed Grain Dust	0	0	2	.3	0	0	14	1.9	0	0	0	0
10	Acco Dust No. 7	0	0	2	.3	0	0	18	2.4	0	0	0	0
11	Wienert's Compound	0	0	1	.2	1	.2	21	2.8	0	0	2	.2
12	Germisan [1]	0	0	0	0	0	0	19	2.7	1	.2	1	.1

[1] 0.25 per cent solution, one hour.

They seem to indicate, however, that none of the treatments used was wholly satisfactory, especially in the variety which showed the most infection. Here again, in Wisconsin Pedigree No. 5, it is interesting to note the almost complete absence of loose smut in the controls, as compared with 36.5 per cent loose smut in the controls from the same seed lot grown in the greenhouse. (Table 7.) Evidently conditions in the field were very unfavorable for loose-smut development, as compared with those in the greenhouse.

During the crop seasons of 1928–29 and 1929–30 loose-smut data were taken on 17 varieties of barley grown by J. W. Taylor in ¼₀-acre plots at the Arlington Experiment Farm. The seed of 13 of these varieties had been treated with Ceresan as a general disease preventive. Seed of 4 varieties was sown in triplicate plots, the seed having been treated first with Ceresan or Semesan or left untreated.

All the heads of loose smut in each plot were counted and these data are shown in Table 10. In Tennessee Winter No. 52 both treatments eliminated loose smut the first year, while the second year Semesan allowed 25 smutted heads to appear in this variety, or 2.6 per cent, as much as appeared in the control plots from untreated seed. In Wisconsin Winter the treatments reduced the amount of loose smut to an average 3.7 and 6.6 per cent of that appearing in the control plots the first and second years, respectively. In Orel the amount of loose smut allowed by the treatments the first and second years was 56.5 and 51.5 per cent, respectively, of that appearing in the control plots. In Esaw the first year the plots from treated seed contained an average of 87 per cent as much smut as appeared in the control plots while the corresponding figure for the second year was 80 per cent.

TABLE 10.—*Loose smut in 17 varieties of winter barley grown from seed untreated or treated with Semesan or Ceresan and sown in 1/40-acre plots, 1928–29 and 1929–30*

Plot No.	Variety		Seed treatment	Total heads loose smut in—	
	Name	C. I. No.		1928–29	1929–30
1	Wisconsin Winter	2159	Untreated	3,120	2,100
2	do	2159	Semesan	130	113
3	do	2159	Ceresan	100	162
4	Tennessee Winter	257	do	24	29
5	Tenkow	646	do	40	40
6	Scottish Pearl	277	do	140	80
7	Pidor	901	do	11	21
8	Wisconsin Winter	2159	do	64	120
9	Orel	351	Untreated	62	100
10	do	351	Semesan	30	50
11	do	351	Ceresan	40	53
12	Han River	2163	do	0	11
13	Wisconsin Winter	2167	do	20	75
14	do	2159	do	58	105
15	Tennessee Winter No. 52	3543	Untreated	495	960
16	do	3543	Semesan	0	25
17	do	3543	Ceresan	0	0
18	Alaska	4106	do	0	12
19	Tennessee Winter	3546	do	0	6
20	do	3545	do	63	60
21	Wisconsin Winter	2159	do	166	70
22	Tennessee Winter	3534	do	5	5
23	Esaw	----------	Untreated	2,790	702
24	do	----------	Semesan	2,590	606
25	do	----------	Ceresan	2,280	520
26	Wisconsin Winter	2159	do	150	43
27	Beardless No. 5	3384	do	315	----------
28	Beardless No. 6	2746	do	450	66
29	Wisconsin Winter	2159	do	140	65
30	Nakano Wase	754	do	60	20

Since untreated seed of the other 13 varieties was not sown, it is not known to what extent, if any, loose smut was controlled in these. The data show, however, that it was not completely eliminated in any of them, although its occurrence may have been reduced considerably. It seems that some other form of treatment, presumably a liquid, would have to be used to secure complete control of loose smut in most of these varieties.

EFFECT OF ENVIRONMENTAL CONDITIONS ON THE DEVELOPMENT AND CONTROL OF LOOSE SMUT

Much has been published on the effect of soil temperature, moisture, reaction and type, and other environmental factors during the period of germination and early growth on the development of a number of seed-borne cereal diseases. The rather voluminous literature on this subject has been admirably reviewed by Reed and Faris (*13*). However, the relation of environment to the development of loose smut in barley seems to have received relatively little study, as not much on this subject appears in the literature. Seiffert (*15*) found that shallow-sown seed produced less infection than seed deeply sown. This same result was observed in experiments at the Arlington Experiment Farm by Taylor and Zehner (*16*). Lind (*11*) reports that the addition of Chile saltpeter, superphosphate, and potash to the soil, alone or in various combinations, slightly increased

the percentage of barley loose smut in six out of seven plots. Kirby (*6*) intimates that infection is favored by soil temperatures higher than those most favorable for the best growth of the barley seedling.

While the main purpose of the experiments described in the preceding pages was to test the relative efficiency of different fungicides in smut control, incidental observations were made in an attempt to correlate the relative severity of loose-smut infection with variations in soil moisture and soil temperature. In Table 1, for example, the soil in series 1 was about 45 per cent saturated at the time of sowing, while in series 2 it was about 65 per cent saturated. The percentage of loose smut in series 1 was twice as great as that in series 2, while control of loose smut was better in series 2. In addition to the higher soil moisture, however, a slightly lower average soil temperature in series 2 may have played some part in this difference.

The same correlation between soil moisture and percentage of loose smut seems to obtain in Table 2. When series 1 was sown the soil was 13 per cent saturated, and when series 2 was sown it was 65 per cent saturated. Here, again, more loose smut developed in the drier soil, and better control was secured in the wetter soil.

Again, in Table 4 it will be observed that in Tennessee Winter barley 2.5 per cent loose smut appeared in the controls of series 2, as compared with 4.5 per cent in the drier soil of series 3, and in both varieties the control of loose smut was better in the wetter soil of series 2.

Similar differences are evident in Table 6. In series 1, in which the soil was 40 per cent saturated when the seed was sown, more smut appeared than in series 2, in which the soil was 75 per cent saturated at the time of sowing. Control again was better in the wetter soil, although here again temperature and fertility relations may have played some part.

The significance of these results, like those relating to control of loose smut by the fungicides used, is greatly decreased by the low percentages of infection in the controls, also by the many unknown factors which enter into field experiments of this kind. To supplement these rather fragmentary field data on the relation of certain environmental factors to the development of loose smut in barley and its control, a number of experiments were conducted in the greenhouse under more or less controlled conditions. In the first of these Wisconsin Pedigree No. 6 barley was grown in metal cans 8 inches in diameter and 12 inches deep, using four lots of soil at 35, 55, 75, and 95 per cent of saturation, respectively. The soil temperature varied from 12° to 18° C. After all the plants had fully emerged they were transferred to the greenhouse bench, where they were grown until final data on loose smut were taken. These data are shown in Table 11. They indicate that, at least in this variety, a high degree of soil moisture from sowing to emergence somewhat inhibits the development of loose smut.

TABLE 11.—*Relation between percentage of soil saturation from planting to emergence and subsequent development of loose smut in Wisconsin Pedigree No. 6 barley*

Soil saturation	Plants			Heads		
	Total	Infected with loose smut		Total	Infected with loose smut	
		Number	*Per cent*		*Number*	*Per cent*
35 per cent	356	63	17.7	474	77	16.2
55 per cent	325	51	15.7	346	54	15.6
75 per cent	311	37	11.9	327	37	11.3
95 per cent	139	4	2.9	159	5	3.1

During the 1929–30 season treated and untreated seed of Wisconsin Pedigree No. 5 barley was used in a greenhouse experiment designed to show the effect of soil moisture on the development and control of loose smut. A greenhouse bench 42 inches wide was divided into three sections each 16 feet long. The soil in these sections, 1, 2, and 3, was adjusted to 37, 64, and 73 per cent, respectively, of its water-holding capacity. The seed was treated with Ceresan and sown 1½ inches deep in rows 6 inches apart, and every eighth row was sown with untreated seed of the same seed lot. Sections 1 and 2 were covered with canvas until the seedlings emerged, while section 3 was watered daily so that at times the water content of the soil undoubtedly was much over 73 per cent of its water-holding capacity. The average temperature in the greenhouse was 15° C. After the seedlings had emerged a test showed that the soil in sections 1, 2, and 3 contained 25, 57, and 70 per cent, respectively, of its water-holding capacity.

When the plants were fully headed they were carefully pulled and counts were made to determine the percentage of disease in each section. Since considerable covered smut and stripe disease developed, data were taken also on these diseases. These data are shown in Table 12.

TABLE 12.—*Relation of soil moisture to development and control of stripe disease, loose smut, and covered smut in Wisconsin Pedigree No. 5 barley grown from untreated seed and seed treated with Ceresan and sown in the greenhouse under three conditions of soil moisture, 1928–29*

Soil saturation	Treated or untreated seed	Total number of plants	Plants infected with—					
			Stripe disease		Loose smut		Covered smut	
			Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
70 to 73 per cent	Untreated	64	6	9.4	8	12.5	2	3.1
	Treated	181	0	0	1	.6	0	0
57 to 64 per cent	Untreated	50	4	8.0	6	12.0	3	6.0
	Treated	136	0	0	0	0	0	0
25 to 37 per cent	Untreated	82	12	14.6	28	34.1	15	18.2
	Treated	199	1	.5	0	0	0	0
Total or average	Untreated	196	22	11.2	42	21.4	20	10.2
	Treated	516	1	.2	1	.2	0	0

In the controls all three diseases developed most abundantly at the lowest soil moisture. Contrary to expectations, however, the only smutted plant from treated seed was found growing in the wettest

soil. However, it was in a row adjacent to a control row, and since this section had been watered freely after being sown, it is probable that an untreated infected kernel was washed from the near-by control row. On the other hand, the only stripe-diseased plant from treated seed was found in the driest soil. The results from this experiment are in agreement with those from the preceding experiment as far as soil moisture and loose-smut development are concerned.

In another experiment seed of Wisconsin Pedigree No. 5 barley was sown in 8-inch cans in each of 16 soil-temperature tanks to determine, if possible, the influence of soil temperature and soil moisture upon loose-smut development. Four soil temperatures were maintained: 10°, 15°, 20°, and 25° C. In each tank the soil in half the number of 8-inch cans was adjusted to 74.1 per cent and in the other half to 42.5 per cent of its water-holding capacity. The construction and operation of the equipment used have been previously described (*7*).

When the plants reached the third-leaf stage they were transplanted to a greenhouse bench, where they were allowed to grow until fully headed. When fully headed the plants were pulled and counts made of healthy and diseased plants and heads. (Tables 13 and 14.) The data presented in Table 13 indicate that the higher soil temperatures were somewhat more favorable for loose-smut infection, especially in the wetter soil. However, there was not enough reduction in the percentage of loose smut at the lowest temperature (10° C.) to explain its almost total absence in plants grown from this same lot of seed in the field at slightly lower and higher average soil temperatures. (Tables 6 and 9.)

TABLE 13.—*Loose smut in Wisconsin Pedigree No. 5 barley grown from naturally inoculated seed sown in the greenhouse, the plants being grown to the fourth-leaf stage under controlled conditions of soil temperature and soil moisture, 1929–30*

Replication No.	Mean soil temperature	Soil 74.1 per cent saturated			Soil 42.5 per cent saturated		
		Total heads	Smutted heads		Total heads	Smutted heads	
	°C.	*Number*	*Number*	*Per cent*	*Number*	*Number*	*Per cent*
1	24.7	92	43	46.7	95	38	40.0
2	25.3	81	37	45.7	80	32	40.0
3	25.2	87	33	37.9	67	16	23.9
4	24.7	93	29	31.2	84	20	23.8
Total or average	25.0	353	142	40.2	326	106	32.5
1	19.8	92	34	37.0	81	22	27.2
2	20.0	80	31	38.8	81	25	30.9
3	20.4	88	40	45.5	94	37	39.4
4	19.8	90	34	37.8	84	21	25.0
Total or average	20.0	350	139	39.7	340	105	30.9
1	16	86	28	32.6	93	28	30.1
2	15.3	68	15	22.1	80	22	27.5
3	15.1	73	25	34.2	80	22	27.5
4	15.1	92	29	31.5	90	19	21.1
Total or average	15.4	319	97	30.4	343	91	26.5
1	11.3	72	15	20.8	73	27	37.0
2	10.0	72	14	19.4	75	16	21.3
3	10.7	64	11	17.2	79	15	19.0
4	10.7	79	28	35.4	71	20	28.2
Total or average	10.7	287	68	23.7	298	78	26.2

TABLE 14.—*Stripe disease, loose smut, and covered smut in Wisconsin Pedigree No. 5 barley grown in the greenhouse from naturally inoculated seed, the plants being grown to the fourth-leaf stage under controlled conditions of soil temperature and soil moisture, 1929–30*

Replication No.	Mean soil temperature	Soil 74.1 per cent saturated			Soil 42.5 per cent saturated		
		Stripe disease	Loose smut	Covered smut	Stripe disease	Loose smut	Covered smut
	° C.	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1	24.7	9.1	40.3	29.9	5.3	40.0	32.0
2	25.3	6.5	40.3	28.6	7.8	35.1	27.3
3	25.2	2.5	37.0	38.3	4.5	23.9	30.0
4	24.7	1.2	32.5	49.4	6.9	21.9	31.5
Average	25	4.7	37.4	36.8	6.2	30.5	30.1
1	19.8	13.6	30.8	46.9	11.4	26.6	54.4
2	20.0	17.7	33.0	38.0	7.9	28.9	47.4
3	20.4	16.4	39.7	41.1	18.0	32.6	44.9
4	19.8	18.4	31.0	41.7	19.3	22.9	43.4
Average	20.0	16.6	33.4	42.2	14.4	27.8	47.6
1	16	18.5	28.4	38.3	12.9	24.6	36.3
2	15.3	8.4	20.8	41.6	20.9	25.5	36.0
3	15.1	15.8	29.2	28.0	21.5	22.7	28.4
4	15.1	14.9	26.4	32.2	12.9	20.4	32.2
Average	15.4	14.6	26.4	34.8	17.2	23.2	33.1
1	11.3	22.0	16.5	26.4	15.7	30.1	18.1
2	10	20.0	15.3	28.2	9.6	16.9	36.1
3	10.7	20.0	13.8	36.3	8.5	18.3	39.0
4	10.7	15.1	29.1	30.2	13.0	23.4	31.2
Average	10.7	19.3	18.7	30.1	11.7	22.2	31.1

It will be observed in Table 14 that in 12 of the 16 tanks, and at three of the four temperatures, more loose smut developed in the plants grown in the soil which was 74.1 per cent saturated than was found in the plants grown in the drier soil. These results which, according to Student's method (*12*), are significant by odds of 60 to 1, are somewhat the reverse of results obtained in previous experiments, as shown in Tables 1, 2, 4, 6, 11, and 12. In these experiments the soil temperatures invariably were relatively low during the periods of emergence, and in no case were they as uniform as that of the soil in the constant-temperature tanks. It is possible that fluctuating soil temperatures may affect loose-smut development differently than does a constant soil temperature. This remains to be determined.

Reed and Faris (*13*) refer to soil moisture, soil temperature, and soil reaction as "interdependent factors" and infer that the "optimum temperature for infection" may change with a change in the other interdependent factors. In line with this theory it will be noted that slightly more infection occurred in the drier soil at 10° C. than in the wetter soil and that at the other temperatures the reverse was true.

The true relation of soil temperature and soil moisture to loose-smut development in these experiments, however, may have been obscured to a considerable degree by the interaction of stripe disease and covered smut which developed to such an extent that data on the percentage of plants affected by these diseases as well as those affected

by loose smut are shown in Table 14. Stripe disease varied in severity from 1.2 to 22 per cent, while covered smut varied from 18.1 to as high as 54.4 per cent in the different replications. To what extent these diseases inhibited the development of loose smut is a question, but undoubtedly the presence, to such a great extent, of two other competing fungi, the development of both of which also are affected by variations in soil moisture and soil temperature, masked to some extent the true response of loose smut to these environmental conditions and in a sense defeated the purpose of the experiment.

During the 1930–31 season an experiment similar to the one described above was conducted in the constant-temperature tanks (7) in the greenhouse with a lot of barley seed known to be relatively free from diseases other than loose smut. The seed used was of an unknown variety grown on a farm near Oconomowoc, Wis., and had been used in two previous experiments. (Tables 8 and 9.) The approximate soil temperatures used were 10°, 15°, 20°, and 25° C. At each temperature the soil was adjusted to four different percentages of its water-holding capacity, namely, 30, 50, 70, and 90 per cent. Two depths of planting, 1½ and 3 inches, were employed at each temperature and each moisture.

The seed was sown November 3, 1930. The lengths of time required by the differently environed seedlings to emerge are shown in Table 15. When the plants had reached the fourth-leaf stage, they were transferred to the greenhouse bench. Here they were exposed to an 18-hour day until they were fully headed, when final data were taken. These data, presented in Table 16, were disappointing because the percentages of smut which developed were too small to show any significant differences in infection due to soil moisture, soil temperature, or depth of planting the seed. In a previous greenhouse experiment in which a soil temperature of about 15° C. had been maintained (Table 8), 6 per cent of loose smut had occurred in the plants grown from this same seed lot. It had been thought possible that much higher percentages of infection might be obtained under different conditions and thus yield results of value, but this did not prove to be the case.

TABLE 15.—*Influence of soil temperature, soil moisture, and depth of planting on the number of days required for emergence in barley*

Temperature of soil	Days required for emergence of barley seedlings grown from seed sown at depths and in soil with percentage of saturation shown							
	30 per cent		50 per cent		70 per cent		90 per cent	
	1.5 inches	3 inches	1.5 inches	3 inches	1.5 inches	3 inches	1.5 inches	3 inches
10° C.	16	18	13	15	11	13	11	13
15° C.	10	12	8	9	7	8	7	8
20° C.	9	10	6	7	5	6	4	5
25° C.	8	9	5	6	5	6	3	4

TABLE 16.—*Results from an experiment designed to show the effect of soil moisture, soil temperature, and depth of planting upon loose-smut infection in barley, 1930–31*

Soil saturation	Smutted plants from seed sown 3 inches deep in soil maintained at—								Results summarized as to soil moisture		
	10° C.		15° C.		20° C.		25° C.		Total plants	Infected plants	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*		*Number*	*Per cent*
30 per cent	2	2.0	1	1.0	4	4.8	1	1.2	365	8	2.2
50 per cent	1	1.0	4	4.9	5	6.8	5	6.1	336	15	4.5
70 per cent	6	6.4	1	1.3	3	3.8	1	1.2	331	11	3.3
90 per cent	6	5.6	3	3.4	4	4.3	1	1.0	395	14	3.5
Total	15	3.7	9	2.6	16	4.9	8	2.3	1,427	48	3.4

Soil saturation	Smutted plants from seed sown 1.5 inches deep in soil maintained at—								Results summarized as to soil moisture		
	10° C.		15° C.		20° C.		25° C.		Total plants	Infected plants	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*		*Number*	*Per cent*
30 per cent	1	1.0	2	2.0	3	3.5	4	5.8	354	10	2.8
50 per cent	4	3.9	2	1.9	3	3.4	3	3.7	376	12	3.2
70 per cent	0	0	5	5.4	3	4.2	0	0	354	8	2.3
90 per cent	2	1.5	1	.8	2	1.8	1	.9	478	6	1.3
Total	7	1.6	10	2.4	11	3.1	8	2.3	1,562	36	2.3

In the experiments with Wisconsin Pedigree No. 5 barley, described above, the percentage of infected plants from one lot of naturally inoculated seed varied from a slight trace to over 40 per cent. The low percentages of infection (trace to 2.5 per cent) occurred in the field, and the high percentages (12 to 40 per cent) in the greenhouse. In the field the average temperatures during the periods of emergence ranged from 9° to 16° C., while the soil moisture varied from 40 to 75 per cent of saturation.

This range of soil temperature and moisture conditions was duplicated in experiments in the greenhouse (Tables 12, 13, and 14), yet in no case was less than 12 per cent of loose smut obtained. It seems evident that some other unknown factors inhibited the development of loose smut in the field and stimulated it in the greenhouse. The possible influence of fluctuating soil temperature in this connection has been mentioned. Faris (*2*), however, working with barley-covered smut, secured more infection at a varying temperature than at any constant temperature. He also found that the optimum temperature for infection varied with the soil reaction from 10° to 20° C. While soil reaction may exert some influence on loose-smut development, it is hardly probable that, in this case, it was responsible for the lack of infection in the field, because the soil in the greenhouse and in the field was of the same type.

It was thought that the development of loose smut might have been greatly influenced by the abnormally long growing day maintained in the greenhouse by means of electric lights. Garner et al. (*3*) found that in certain plants the length of the daily light period may determine not only the quantity of carbohydrate produced but also its form, its utilization, the acidity of the sap, and the water content of

the tissues. To determine whether the length of the daily light period would influence the development of loose smut, seed of Wisconsin Pedigree No. 5 barley was sown December 5, 1930, in two sections of the greenhouse bench. One section was given a daily 18-hour light period until the plants had headed. The other section received no artificial light. To vary the experiment, half of the seed in each section was artificially smutted with spores of loose smut.

The plants exposed to a daily 18-hour light period were fully headed by March 10, at which time data were taken on the percentage of plants infected with loose and covered smuts. Similar data on the plants which had received a normal daily light period could not be taken until April 15. These data, presented in Table 17, show that the high percentage of loose smut in this variety of barley in previous greenhouse experiments could not be attributed to the abnormally long daily light period to which the plants had been exposed. Table 17 shows that slightly more loose-smut infection occurred in the plants receiving a normal daily light period than in those exposed to additional artificial illumination. This held true for the plants from both smutted and unsmutted seed.

TABLE 17.—*Effect of two different daily light periods on the percentages of loose and covered smuts in Wisconsin Pedigree No. 5 barley grown in the greenhouse (December, 1930, to April, 1931) from seed which was naturally inoculated with both smuts, and half of which was also artificially inoculated with spores of loose smut*

Length of daily light period	Seed artificially smutted or not	Total plants grown	Plants infected with—			
			Loose smut		Covered smut	
			Number	*Per cent*	*Number*	*Per cent*
18-hour day	Not smutted	165	53	32.1	68	41.2
	Smutted	200	106	53	62	31
Normal day	Not smutted	155	62	40	60	38.7
	Smutted	160	88	55	55	34.4

It is probable that other conditions of growth in the greenhouse, different from those in the field, were responsible for the high percentages of loose smut consistently obtained in the greenhouse. Among these may be mentioned the diminished intensity of the light in the greenhouse, which, by making the plants more succulent, may have favored the growth of the smut fungus.

SUMMARY

From the field experiments and observations described it seems evident that dust fungicides are not effective in the control of loose smut in barley except in certain varieties. In those varieties, such as Wisconsin Pedigree No. 5 and Tennessee Winter No. 52, in which natural seed inoculation by the loose-smut fungus evidently takes place somewhat like that by the organisms causing covered smut or stripe disease, the more effective dust fungicides will control the disease. In varieties in which most seed inoculation by the loose-smut fungus takes place apparently like that by the fungus causing loose smut in wheat the hot-water treatment is the only one known to be effective in controlling the disease.

Very wet soil (about 90 per cent saturated) seems to inhibit somewhat the development of loose smut and favors its control by dust fungicides. Very dry soil, containing barely enough moisture to bring about germination and emergence, seems to be conducive to loose-smut development and unfavorable to its control by dust fungicides. Between these two extremes, other conditions remaining the same, variation in soil moisture does not seem to affect greatly the development of loose smut in barley or its control, the percentage of infection usually being less than in very dry soil and more than in very wet soil.

A relatively high soil temperature before emergence seems to favor loose-smut development more than does a low soil temperature. From 20 to 100 per cent more infection occurred at 25° C. than at 10° C. in Wisconsin Pedigree No. 5 barley grown from naturally inoculated seed. Other factors, however, such as the interaction of other diseases caused by seed-borne organisms, may have been largely responsible for these results.

On the whole the data relating to the effects of environmental factors on infection by the barley loose-smut fungus are somewhat fragmentary and incomplete and are presented here more as a preliminary than as a final report. More extensive experiments with a number of varieties are desirable to establish more definitely the relations of these different factors to loose-smut infection in barley. There are indications that the influence of environment is not confined to the period of germination and early growth, but may extend over a considerable part of the life of the plant.

LITERATURE CITED

(1) CONNERS, I. L.
1926. ORGANIC MERCURY COMPOUNDS FOR THE CONTROL OF LOOSE SMUTS OF WHEAT AND BARLEY AND BARLEY STRIPE. (Abstract) Phytopathology 16:63–64.

(2) FARIS, J. A.
1924. FACTORS INFLUENCING INFECTION OF HORDEUM SATIVUM BY USTILAGO HORDEI. Amer. Jour. Bot. 11:189–214, illus.

(3) GARNER, W. W., BACON, C. W., and ALLARD, H. A.
1924. PHOTOPERIODISM IN RELATION TO HYDROGEN-ION CONCENTRATION OF THE CELL SAP AND THE CARBOHYDRATE CONTENT OF THE PLANT. Jour. Agr. Research 27:119–156, illus.

(4) HUMPHREY, H. B., and POTTER, A. A.
1918. CEREAL SMUTS AND THE DISINFECTION OF SEED GRAIN. U. S. Dept. Agr. Farmers' Bul. 939, 28 p., illus.

(5) JOHNSON, A. G.
1914. EXPERIMENTS ON THE CONTROL OF CERTAIN BARLEY DISEASES. (Abstract) Phytopathology 4:46.

(6) KIRBY, R. S.
1927. DISEASES OF SMALL GRAINS. N. Y. Agr. Col. (Cornell) Ext. Bul. 157, 71 p., illus.

(7) LEUKEL, R. W.
1924. EQUIPMENT AND METHODS FOR STUDYING THE RELATION OF SOIL TEMPERATURE TO DISEASES IN PLANTS. Phytopathology 14: [384]–397, illus.

(8) ———
1929. EXPERIMENTS WITH LIQUID AND DUST SEED DISINFECTANTS FOR CONTROLLING COVERED SMUT OF BARLEY AND STINKING SMUT OF WHEAT, 1926–1928. (Abstract) Phytopathology 19:81.

(9) ———
1930. SEED TREATMENT FOR CONTROLLING COVERED SMUT OF BARLEY. U. S. Dept. Agr. Tech. Bul. 207, 23 p., illus.

(10) LEUKEL, R. W., DICKSON, J. G., and JOHNSON, A. G.
1929. EXPERIMENTS ON STRIPE DISEASE OF BARLEY AND ITS CONTROL. (Abstract) Phytopathology 19:81.
(11) LIND, J.
1915. FORSØG MED MIDLER MOD NOGEN BYGBRAND. Tidsskr. Planteavl 22:212–232.
(12) LOVE, H. H., and BRUNSON, A. M.
1924. STUDENT'S METHOD FOR INTERPRETING PAIRED EXPERIMENTS. Jour. Amer. Soc. Agron. 16:60–68.
(13) REED, G. M., and FARIS, J. A.
1924. INFLUENCE OF ENVIRONAL FACTORS ON THE INFECTION OF SORGHUMS AND OATS BY SMUTS. I. EXPERIMENTS WITH COVERED AND LOOSE KERNEL SMUTS OF SORGHUM. II. EXPERIMENTS WITH COVERED SMUT OF OATS AND GENERAL CONSIDERATION. Amer. Jour. Bot. 11:518–534, 579–599.
(14) RODENHISER, H. A., and STAKMAN, E. C.
1925. THE CONTROL OF LOOSE SMUTS OF WHEAT AND BARLEY, AND BARLEY STRIPE BY USPULUN, SEMESAN, AND GERMISAN. (Abstract) Phytopathology 15:51.
(15) SEIFFERT, J.
1926. KÜNSTLICHE BLÜTENINFEKTIONEN ZUR UNTERSUCHUNG DER EMPFÄNGLICHKEIT VERSCHIEDENER GERSTENSORTEN FÜR USTILAGO HORDEI NUDA UNTER EINFLUSS ÄUSSERER BEDINGUNGEN AUF DIE HÖHE DES BRANDPROZENTES. Kühn Arch. 12:423–515.
(16) TAYLOR, J. W., and ZEHNER, M. G.
1931. EFFECT OF DEPTH OF SEEDING ON THE OCCURRENCE OF LOOSE AND COVERED SMUTS IN WINTER BARLEY. Jour. Amer. Soc. Agron. 23:132–141, illus.
(17) TISDALE, W. H., and CANNON, W. N.
1929. ETHYL MERCURY CHLORIDE AS A SEED GRAIN DISINFECTANT. (Abstract) Phytopathology 19:80.
(18) ——— TAYLOR, J. W., and GRIFFITHS, M. A.
1923. EXPERIMENTS WITH HOT WATER, FORMALDEHYDE, COPPER CARBONATE AND CHLOROPHOL FOR THE CONTROL OF BARLEY SMUTS. Phytopathology 13:[153]–160.
(19) ——— TAYLOR, J. W., LEUKEL, R. W., and GRIFFITHS, M. A.
1925. NEW SEED DISINFECTANTS FOR THE CONTROL OF BUNT OF WHEAT AND THE SMUTS OF OATS AND BARLEY. Phytopathology 15: [651]–676.

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TECHNICAL BULLETIN No. 292 APRIL, 1932

THE INHERITANCE OF COLORED SCUTELLUMS IN MAIZE

BY

GEORGE F. SPRAGUE

Assistant Agronomist
Division of Cereal Crops and Diseases
Bureau of Plant Industry

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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Assistant Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry

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INTRODUCTION

In the genetic analysis of maize, genes determining endosperm and seedling characters have occupied a very prominent place. This is in part because of the greater ease of obtaining large numbers. These factors also seem to occur more frequently in the germ plasm of maize than do those affecting the mature plant. The list of reported genes is now well over 200, and of this number fully 150 show their effect in the endosperm or seedling. Genes producing a visible effect in the maize germ have been very few. The scarcity of such genes doubtless is due in part to the fact that they have not been sought.

In 1923 Mangelsdorf (*8*)[3] and Lindstrom (*7*) reported simultaneously on a condition in maize in which there is a failure of a definite proportion of the kernels to go through the normal rest period. The following year Eyster (*3*) reported a similar condition, which he designated "primitive sporophyte." In 1926 Mangelsdorf (*9, p. 607*) reported further on this same condition, designating it "premature

[1] Presented to the faculty of the Graduate School of Cornell University in partial fulfillment of the requirements for the degree of doctor of philosophy.

[2] The writer takes this opportunity to express his indebtedness to R. A. Emerson, under whose supervision these studies were conducted; to Mary Whitworth Sprague for assistance in making counts; to F. D. Richey for suggestions in the presentation of material; and to I. F. Phipps for the original stocks of the dominant white and orange scutellums.

[3] Italic numbers in parentheses refer to Literature Cited, p. 43.

germination" and presenting data from which he concluded that there were "nine Mendelian factors involved in the maintenance of a normal period of dormancy in maize seeds * * *." In 1930 he (*10*) presented additional data and concluded that 15 factor pairs were involved in the production of the nine different types of premature germination. There still remains the possibility, however, that certain of these factors may be genetically identical.

Jenkins (*6*) reported the factor pair *Pu pu* in 1926. The dominant member of this factor pair causes the development of purple color in the plumulary sheath. The writer (*12*) presented evidence that "colored scutellum" was a heritable character of maize and dependent upon the interaction of several factors. This bulletin gives the results of a continuation of the study of the genes concerned in the expression of various scutellum colors.

SOURCE AND DESCRIPTION OF MATERIAL

Data are presented on the inheritance and interaction of five different scutellum colors, namely, purple, red, orange, yellow, and white. The related colors purple and red are dominant to the absence of color, with the exception of one dominant white. The orange and yellow scutellums are recessive to white. In progenies segregating for orange and yellow and for purple or red, orange and yellow scutellums can be determined with accuracy only among the nonpurple and nonred classes.

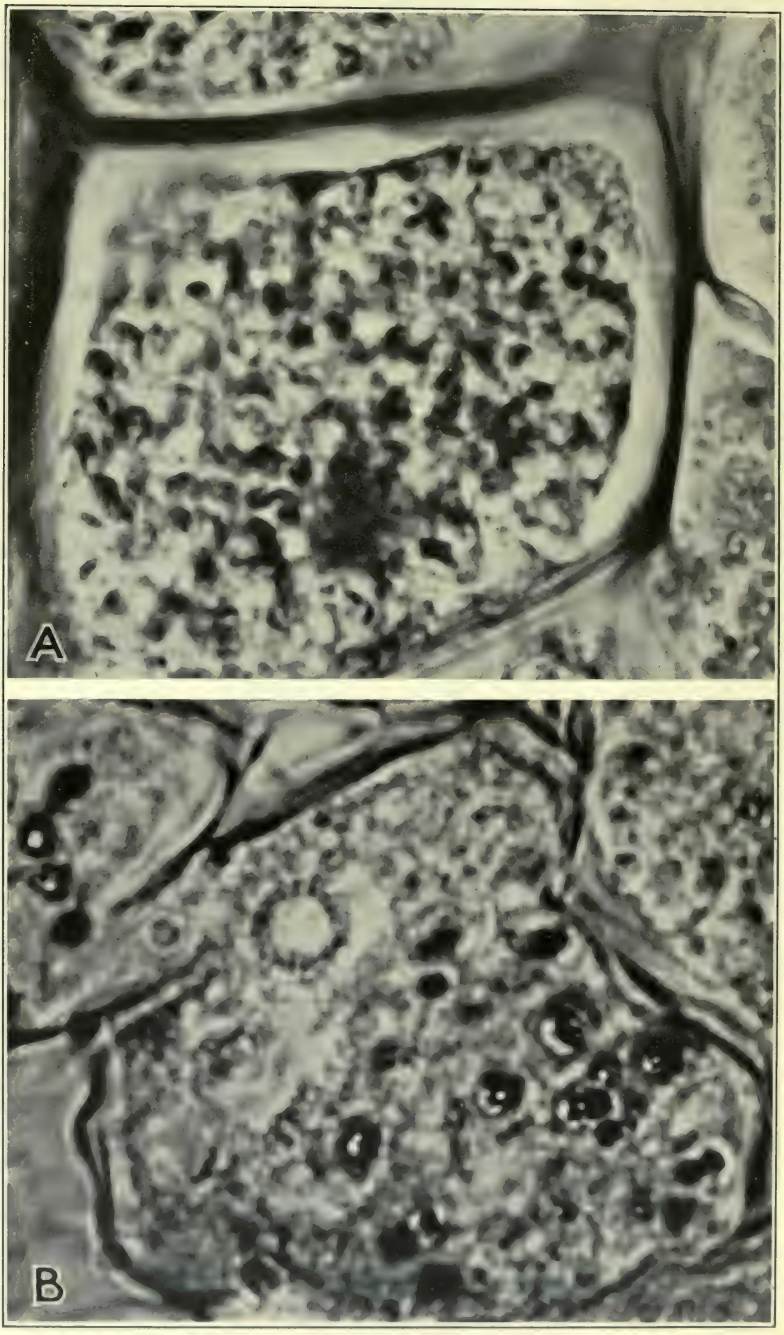
Purple scutellums were first noted at the North Platte (Nebr.) substation of the Nebraska Agricultural Experiment Station in 1923 on a single open-fertilized ear of a local variety known as Blue Flour. True-breeding colored scutellum strains, as well as testers for the purple and red series, were isolated from progeny of this original ear.

A selfed ear obtained from I. F. Phipps at Cornell University was segregating in a ratio of 9 colored to 55 white scutellums. A dominant white was isolated from the progeny of this ear. Scutellums most commonly are white, but with the exceptions of this one gene white has been recessive to purple and red.

Orange scutellums first were observed by Doctor Phipps in a single ear from one of his pedigrees. This ear was segregating in a ratio of 3 white to 1 orange. Other ears from the same pedigree exhibited similar ratios or ratios of 15 whites to 1 orange. Orange scutellums have not been observed by the writer in any material not tracing back to this original source.

Yellow scutellums were observed in the selfed progeny of the original Blue Flour ear. This color was found to be dependent on a single gene recessive to normal white. Several stocks involving South American parentage in Doctor Emerson's cultures were found to be segregating for yellow scutellums. These were tested with the writer's yellow and were found to be identical with it.

Cross sections of colored scutellum kernels through the germ show that the color is confined to the scutellum, the plumule and radicle being colorless. The intensity and distribution of color in the orange and yellow scutellums is fairly uniform. In the purples and reds the color may range from very pale to very dark in different kernels



ALEURONE GRAINS

A, In the aleurone layer; B, in the scutellum. × 2,500.

of the same ear. This difference in coloration is dependent in part upon the number of homozygous dominant scutellum factors present and may also be influenced by a concomitant variation in aleurone color. It follows that the segregating ears are subject to greater variation among the colored segregates than are homozygous ears.

In some kernels pigmentation is more intense immediately surrounding the embryo; in others it reaches its greatest intensity near the epithelial layer. The expression of color is fairly clear cut, and segregation is sufficiently sharp in most pedigrees so that no serious trouble has been experienced in classification. It has been found necessary, however, to cut into each scutellum to be certain of the correctness of its classification. This can be done in such a manner as to cause little decrease in germination and survival.

LOCATION OF SCUTELLUM PIGMENTS

Investigators who have studied the pigmentation in the aleurone of maize are agreed that the coloring matter is located in the aleurone grains. No mention could be found of the occurrence of aleurone grains in the maize scutellum.

Material for a study of the location of scutellum colors was fixed in formyl-alcohol at intervals of 5, 10, 14, 19, and 24 days after pollination. The material was then dehydrated, infiltrated with paraffin, and sectioned 10 to 12 microns thick. The most satisfactory stain combination of those tried was safranine and gentian violet in aniline oil.

The fixative was not suitable for studying the early development of aleurone grains. It was found, however, that aleurone grains were not recognizable in the material fixed 10 days after pollination but were present in the 14-day-old material. These periods undoubtedly will differ under other environmental conditions. Aleurone grains appeared in the scutellum at approximately the same time as in the aleurone layer.

In the material fixed 14 days after pollination aleurone grains were abundant in the scutellum. Near the plumule and radicle the grains apparently were fewer. This may have been more apparent than real. Cells in this region are densely protoplasmic, and aleurone grains might easily be obscured. The relatively undifferentiated parenchymatous cells in the scutellum are best suited for the study of aleurone grains.

In the aleurone layer these grains are easily distinguishable. The layers of cells underlying the aleurone layer also contain aleurone grains. The number of grains apparently decreases with each successive cell layer.

Material fixed 19 and 24 days after pollination looked very much alike. (Pl. 1.) The aleurone grains in the scutellum had increased greatly in size. In the aleurone layer the increase in size was not marked, but there was an increase in number. Aleurone grains in the scutellum were examined in free-hand sections, mounted in glycerin, observed under an oil-immersion lens. In purple, red, yellow, and orange scutellums the coloring matter appeared to be concentrated in the irregular envelope of the aleurone grain, with the remainder of the grain nearly colorless.

RELATION OF SCUTELLUM AND ALEURONE COLORS

Orange or yellow scutellums are not dependent upon the *A-C-R-Pr-i* aleurone genes or upon the genes for brown aleurone; that is, these colors may occur in kernels having purple, red, brown or colorless aleurone. Orange scutellums are dependent for their expression upon two recessive genes so_1 and so_2, while yellow scutellums are dependent upon only the single recessive gene *sy*.

The purple and red scutellums present an entirely different situation. These colors are dependent upon four dominant genes, S_1, S_2, S_3, and S_4, which may exhibit various types of interaction. In progenies segregating for both aleurone and scutellum color only those kernels having purple or red aleurone normally have colored scutellums.

The basic aleurone factors *A-C-R-pr* and *i* in the presence of the necessary scutellum factors will result in red scutellums. If recessive *pr* is replaced by its dominant allelomorph, *Pr*, the aleurone and scutellum color is purple. This relationship is illustrated by the data in Table 1.

It may be concluded from these data that the *Pr pr* factor pair differentiates purple and red scutellums.

With *I* in either a homozygous or heterozygous condition no purple or red develops in the scutellums. Similarly when *A*, *C*, or *R* is recessive, only colorless scutellums normally are produced. In progenies segregating for scutellum and aleurone genes, scutellar segregations can be observed only in the colored aleurone class. This relationship is illustrated for the *Ii*, *Rr*, *Aa*, and *Cc* factor pairs in Tables 2, 3, 4, and 5, respectively.

Among the progenies listed in Tables 3, 4, and 5 occur a few kernels having colorless aleurone and colored scutellums. This seems a direct contradiction of the interaction described above. When these kernels were planted, however, they produced progenies whose segregations for aleurone color were typical of those usually obtained from colored aleurone seeds that are heterozygous. Numerous tests have shown that the embryo and endosperm of such kernels are of different genetic constitutions and that the embryo always possesses the factors necessary for aleurone color. This condition has been reported by the writer (*13*) under the term "heterofertilization."

TABLE 1.—*Records of scutellum color in 10 F_2 progenies of crosses of purple and red scutellums*

Pedigree No.	Purple aleurone		Red aleurone	
	Purple scutellum	Red scutellum	Purple scutellum	Red scutellum
336-8	100	0	0	34
381-1	179	0	0	75
381-2	201	0	0	58
381-4	172	0	0	71
381-5	175	0	0	54
381-8	123	0	0	36
381-9	143	0	0	62
381-12	208	0	0	82
381-15	179	0	0	76
381-16	65	0	0	29
Total	1,545	0	0	576

TABLE 2.—*Records of scutellum color in 10 F_3 progenies of crosses of dominant white aleurone × colored scutellums*

Pedigree No.	Colored aleurone		Colorless aleurone	
	Colored scutellum	Colorless scutellum	Colored scutellum	Colorless scutellum
198–2	34	13	0	198
198–4	19	7	0	116
198–5	75	20	0	423
198–6	86	28	0	498
198–8	45	18	0	286
198–10	32	9	0	181
198–12	36	10	0	190
198–14	56	19	0	331
198–15	28	11	0	169
198–17	15	7	0	87
Total	426	142	0	2,479

TABLE 3.—*Records of scutellum color in seven F_3 progenies of F_2 kernels having colorless aleurone (A C r) and colored scutellum*

Pedigree No.	Colored aleurone		Colorless aleurone	
	Colored scutellum	Colorless scutellum	Colored scutellum	Colorless scutellum
550–1	252	18	1	81
561–1	46	13	0	22
561–2	81	106	2	70
561–3	125	48	2	59
590–1	151	7	5	47
590–3	122	13	1	30
590–5	180	12	3	40

TABLE 4.—*Records of scutellum color in 10 F_3 progenies of F_2 kernels having colorless aleurone (a C R) and colored scutellum*

Pedigree No.	Colored aleurone		Colorless aleurone	
	Colored scutellum	Colorless scutellum	Colored scutellum	Colorless scutellum
580–1	127	31	0	57
583–2	148	59	1	61
583–3	156	50	0	65
585–1	56	67	1	24
586–1	294	16	3	93
586–2	122	20	3	33
588–1	264	2	1	72
596–1	119	81	0	48
598–1	67	8	0	26
598–2	155	29	1	53

TABLE 5.—*Records of scutellum color in 11 F_3 progenies of F_2 kernels having colorless aleurone (A c R) and colored scutellum*

Pedigree No.	Colored aleurone		Colorless aleurone	
	Colored scutellum	Colorless scutellum	Colored scutellum	Colorless scutellum
561-1	46	13	0	22
561-2	81	106	2	70
561-3	125	48	2	59
567-1	168	54	4	75
575-1	178	58	0	77
577-1	96	84	1	56
579-4	231	16	1	77
582-5	73	103	0	62
587-1	227	10	0	82
587-2	111	10	0	53
597-2	250	84	0	125

In progenies segregating for scutellum color and the aleurone pattern factor "Navaho," the segregations for scutellum color can be determined among both self-colored and Navaho classes. The data illustrating this behavior are presented in Table 6.

TABLE 6.—*Records of scutellum color in five F_3 progenies of F_2 colored scutellum kernels heterozygous for the Navaho pattern factor*

Pedigree No.	Number of individuals			
	Self-colored aleurone		Navaho aleurone	
	Colored scutellum	Colorless scutellum	Colored scutellum	Colorless scutellum
995-9	190	56	66	17
995-12	229	80	95	29
995-14	150	51	81	15
Total	569	187	242	61
995-3	194	10	70	3
995-10	134	10	55	4
Total	328	20	125	7

A similar situation exists with respect to the pattern factors "stipple" (Tables 7 and 8) and "blotch." (Table 9.) In the data of both Tables 7 and 8 the stippled aleurone class is deficient on the basis of a 3:1 segregation. This deficiency for the data in Table 7 may be due to a faulty classification. In Table 8 the percentage of stippled individuals suggests a duplicate gene relationship. Colored scutellums are exhibited in the presence of blotch, as shown by the data in Table 9.

TABLE 7.—*Records of scutellum color in five F_2 progenies of the cross self-colored aleurone, colored scutellum, × stipple aleurone, colorless scutellum*

Pedigree No.	Number of individuals			
	Self-colored aleurone		Stippled aleurone	
	Colored scutellum	Colorless scutellum	Colored scutellum	Colorless scutellum
838-1	187	14	53	4
838-2	245	17	42	3
838-3	174	13	52	4
838-4	276	12	72	5
838-5	175	12	67	6
Total	1,057	68	286	22

TABLE 8.—*Records of scutellum color in six F^2 progenies of the cross self-colored aleurone, colored scutellum, × stipple aleurone, colorless scutellum*

Pedigree No.	Number of individuals			
	Self-colored aleurone		Stippled aleurone	
	Colored scutellum	Colorless scutellum	Colored scutellum	Colorless scutellum
839-1	222	16	24	3
839-4	247	27	15	9
839-5	229	19	23	4
839-6	121	14	9	2
839-8	203	19	15	3
839-9	246	28	14	6
Total	1,268	123	100	27

TABLE 9.—*Records of scutellum color in six progenies segregating for blotch aleurone grown from heterofertilized kernels*

Pedigree No.	Number of individuals			
	Blotch aleurone		Colorless aleurone	
	Colored scutellum	Colorless scutellum	Colored scutellum	Colorless scutellum
990-1	138	12	3	61
990-3	180	11	25	76
990-5	127	12	9	33
990-6	71	6	16	72
990-7	173	15	6	65
990-13	65	6	0	22

The classification of scutellum color in stipple and blotch kernels is not so satisfactory as in self-colored or Navaho kernels. In the presence of the pattern factors stipple and blotch there is a strong tendency for the scutellum color to be restricted to a small area near the radicle.

NONALLELOMORPHISM OF SCUTELLUM AND ALEURONE FACTORS

The dependency of scutellum color upon aleurone color suggests that possibly the scutellum and aleurone factors are allelomorphic. Data do not bear out this suggested relationship. Let us, for the purpose of illustration, assume one of the complementary scutellum factors to be allelomorphic to *C*, designating it C^{sc}. A cross between a colored aleurone, colored scutellum strain, and a colorless aleurone, colorless scutellum strain, having the allelomorph *c*, should produce the following types and frequencies in F_2: 1 C^{sc} C^{sc}: 2 C^{sc} *c*: 1 *c c*. Only parental types should appear in F_2 or subsequent generations. Actually from every such cross studied a new type, colored aleurone, colorless scutellum, has appeared in F_2. This type can be extracted in a true breeding condition in F_3. This precludes the possibility of allelomorphism of scutellum and aleurone factors.

PURPLE AND RED SCUTELLUMS

For the sake of simplicity it is advisable to consider the inheritance of the related colors purple, red, and recessive white, apart from dominant white, orange, and yellow. The latter show a relatively simple mode of inheritance, whereas the behavior of the purples and reds is more complex.

Segregates from crosses of colored × colored, colored × colorless, and colorless × colorless scutellums have been studied. Some of the data on such progenies are presented in Table 10.

In addition to progenies exhibiting colored scutellums only and others segregating in the simple ratio of 3 colored scutellums to 1 colorless, other ratios were obtained indicative of a complex system of factor interaction.

The data in Groups 2 and 3 of Table 10 approximate 9 to 7 and 27 to 37 ratios, indicating complementary genes. Students of corn genetics are well acquainted with this type of interaction, exemplified by the well-known series of aleurone factors. The data in Group 4, on the other hand, suggest the action of duplicate genes. The ratios in Groups 5 and 6 of the same table suggest a combination of these two types of behavior.

THE SUGGESTED HYPOTHESIS

The following hypothesis has been formulated to account for these various ratios. Four factor pairs, S_1 s_1, S_2 s_2, S_3 s_3, and S_4 s_4, are postulated. Of this series, S_1 always must be present if purple or red scutellums are to result. In addition to S_1, the dominant allelomorphs of any two of the other three members of the series are required for the development of colored scutellums.

TABLE 10.—*Records of scutellum color in 108 segregating progenies of crosses of colored × colorless, colorless × colorless, and colored × colored parents*

Group and pedigree No.	Number of individuals			Percentage colorless	Dev. / P. E.
	Colored	Colorless	Total		
Group 1 (3 : 1):					
100–1	326	101	427	23.7	1.0
100–2	233	84	317	26.5	.9
100–3	299	90	389	23.1	1.3
100–4	400	125	525	23.8	.9
100–7	373	110	483	22.8	1.7
100–8	348	127	475	26.7	1.3
100–10	407	140	547	25.6	.5
100–12	332	100	432	23.1	1.3
100–13	436	150	586	25.6	.5
100–16	340	110	450	24.4	.4
170–1	123	40	163	24.5	.2
170–2	125	36	161	22.4	1.1
170–4	81	24	105	22.9	.8
178–5	200	58	258	22.5	1.4
320–1	196	45	241	18.7	3.4
320–4	148	57	205	27.8	1.4
321–4	291	90	381	23.6	.9
321–5	320	91	411	22.1	2.0
322–1	159	37	196	18.9	2.9
322–2	66	15	81	18.5	2.0
322–3	251	62	313	19.8	3.1
322–6	217	80	297	26.9	1.1
323–2	227	72	299	24.1	.5
323–4	227	75	302	24.8	.1
323–5	183	58	241	24.1	.5
323–7	341	100	441	22.7	1.7
323–8	199	42	241	17.4	4.0
323–10	328	114	442	25.8	0.6
323–11	247	95	342	27.8	1.8
323–12	240	99	339	29.2	2.6
323–1	205	72	277	26.0	.6
324–1	182	41	223	18.4	3.4
324–7	224	55	279	19.7	3.0
325–1	160	59	219	26.9	1.0
325–8	179	65	244	26.6	.9
327–1	171	71	242	29.3	2.3
327–4	171	73	244	29.9	2.6
327–10	193	46	239	19.2	3.0
327–11	206	47	253	18.6	3.5
327–12	198	46	244	18.9	3.3
328–5	38	12	50	24.0	.2
329–1	205	55	260	21.2	2.1
329–5	217	55	272	20.2	2.7
Total	10,012	3,124	13,136	23.8	4.8
Group 2 (9 : 7):					
104–5	122	75	197	38.1	2.4
104–7	231	149	380	39.2	2.6
170–3	132	114	246	46.3	1.2
320–8	129	80	209	38.3	2.4
320–11	198	142	340	41.8	1.1
323–9	150	131	281	46.6	1.4
324–2	195	101	296	34.1	4.9
324–4	149	103	252	40.9	1.4
324–5	163	120	283	42.4	.7
324–7	132	127	259	49.0	2.5
324–10	186	124	310	40.0	2.0
325–5	153	124	277	44.8	.5
327–7	141	119	260	46.8	1.0
328–6	95	91	186	48.9	2.1
329–6	187	141	328	43.0	.4
Total	2,363	1,741	4,104	42.4	2.5
Group 3 (27 : 37):					
170–5	71	162	233	69.5	5.4
322–8	118	221	339	65.2	4.1
322–13	98	205	303	67.7	5.2
4–1	166	230	396	58.1	.1
102–6	259	366	625	58.6	.5
103–8	230	334	564	59.2	1.0
103–11	96	160	256	62.5	2.3
322–4	122	144	266	54.1	1.5
322–12	176	198	374	52.9	2.8
325–4	102	115	217	53.0	2.1
325–7	88	95	183	51.9	2.4

TABLE 10.—*Records of scutellum color in 108 segregating progenies of crosses of colored × colorless, colorless × colorless, and colored × colored parents*—Continued

Group and pedigree No.	Number of individuals			Percentage colorless	Dev. P. E.
	Colored	Colorless	Total		
Group 3 (27 : 37)—Continued.					
325-6	67	85	152	55.9	0.7
327-2	107	162	269	60.2	1.2
327-5	84	122	206	59.2	.6
327-6	121	171	292	58.6	.4
327-8	118	124	242	51.2	3.1
327-9	99	120	219	54.8	1.3
328-1	121	134	255	52.5	2.6
328-2	104	124	228	54.4	1.5
328-4	86	105	191	55.0	.3
Total	2,433	3,377	5,810	58.1	.7
Group 4 (15 : 1):					
4-3	275	18	293	6.1	.1
4-4	163	13	176	7.4	.9
4-5	327	27	354	7.6	1.6
101-2	473	39	512	7.6	1.9
101-5	344	29	373	7.8	1.8
101-7	354	30	384	7.8	1.9
188-12	163	11	174	6.3	0
320-10	141	14	155	9.0	2.1
321-6	235	24	259	9.3	3.0
322-7	168	20	188	10.6	3.7
322-11	281	9	290	3.1	3.3
323-13	320	24	344	7.0	.8
323-14	276	11	287	3.8	2.5
323-3	160	8	168	4.8	1.2
328-3	211	16	227	7.0	.7
329-4	273	24	297	8.1	1.9
323-7	233	19	252	7.5	1.3
Total	4,397	336	4,733	7.1	3.6
Group 5 (54 : 10):					
320-2	256	33	289	11.4	2.9
320-3	246	33	279	11.8	2.6
320-9	262	45	307	14.7	.7
321-1	293	51	344	14.8	.6
324-6	155	26	181	14.4	.7
324-11	190	23	213	10.8	2.8
329-3	207	39	246	15.9	.1
322-7	168	20	188	10.6	2.8
Total	1,777	270	2,047	13.2	4.5
Group 6 (162 : 94):					
866-3	113	60	173	34.7	.9
866-4	75	39	114	34.2	1.0
866-8	136	68	204	33.3	1.6
867-2	86	57	143	39.9	1.1
867-7	101	58	159	36.5	.1
868-1	78	29	107	27.1	3.1
Total	589	311	900	34.6	2.0

Four wholly homozygous stocks of colored scutellums are then possible. These are:

$S_1\ S_1,\ S_2\ S_2,\ S_3\ S_3,\ S_4\ S_4$
$S_1\ S_1,\ S_2\ S_2,\ S_3\ S_3,\ s_4\ s_4$
$S_1\ S_1,\ S_2\ S_2,\ s_3\ s_3,\ S_4\ S_4$
$S_1\ S_1,\ s_2\ s_2,\ S_3\ S_3,\ S_4\ S_4$

Selfed parents giving rise to ratios of 3 colored to 1 colorless scutellum may be of 1 of 4 major classes of genotypes, namely:

A: $S_1\ s_1,\ S_2\ S_2,\ S_3\ S_3,\ S_4\ S_4$
B: $S_1\ s_1\ (S_2\ S_2,\ S_3\ S_3,\ S_4\ s_4)$
C: $S_1\ s_1\ (S_2\ S_2,\ S_3\ s_3,\ s_4\ s_4)$
D: $S_1\ S_1\ (S_2\ S_2,\ S_3\ s_3,\ s_4\ s_4)$

Classes A, B, and C are alike in having S_1 s_1 heterozygous with at least two of the other members of the series homozygous dominant. It is immaterial which member of the series inclosed in parentheses is heterozygous in class B orhomozygous in class C, thus giving three subtypes within each of these two classes, all of which will segregate in the 3 : 1 ratio. The colorless scutellum segregates from classes A, B, and C will be specific testers for the S_1 s_1 factor pair. If also recessive for one of the other members of the series, they will incidentally be testers for that member when used with certain genotypes.

Class D differs basically from A, B, and C in having S_1 S_1 homozygous dominant, with segregation due to the other members of the series. Here, it is immaterial which one of the three factor pairs, S_2, S_3, or S_4, is dominant, which one is heterozygous, and which one is recessive. The colorless scutellum segregates will be recessive for two of the factors within parentheses. They therefore will constitute testers for these two factors together or will determine that one of the two is concerned, but will not differentiate between them.

Ratios of 9 colored to 7 colorless scutellums are expected when any 2 factor pairs are heterozygous, and if in addition 1 of the factor pairs S_2, S_3, and S_4 is homozygous recessive.

Similarly, if one member of the series S_2, S_3, and S_4 is homozygous recessive, the two remaining members and S_1 being heterozygous, ratios of 27 colored to 37 colorless scutellums are expected. This and the preceding ratios comprise the complementary series.

Ratios of 15 colored to 1 colorless scutellum are to be expected when S_1 and 1 member of the series S_2, S_3, and S_4 are homozygous dominant and the other 2 members are heterozygous. White segregates from such ratios would be expected to constitute testers for the two genes recessive or will determine that one of the two is concerned, but will not differentiate between them. This ratio with its 3 : 1 components constitutes the duplicate series.

The remaining ratio types expected on the basis of the hypothesis are combinations of the complementary and duplicate series.

The ratio expected when 1 member of the series S_2, S_3, and S_4 is homozygous dominant and the remaining 3 factors are heterozygous is 45 colored to 19 colorless scutellums.

Ratios of 54 colored to 10 colorless scutellums are expected when S_1 is homozygous dominant and the factors S_2 s_2, S_3 s_3, and S_4 s_4 are heterozygous.

The most complex ratio obtainable under the hypothesis is 162 colored to 94 colorless scutellums. This ratio would be expected if all four of the factors S_1 s_1, S_2 s_2, S_3 s_3, and S_4 s_4 were heterozygous.

The following diagram provides a detailed illustration of the various genotypes that may be involved in the production of each ratio type. All genotypes recessive for s_1 s_1 are omitted, as colorless scutellums would result.

	S_1 S_1	S_1 s_1
S_2 S_2, S_3 S_3, S_4 S_4	Colored	3 : 1
S_2 S_2, S_3 S_3, S_4 s_4	Colored	3 : 1
S_2 S_2, S_3 s_3, S_4 S_4	Colored	3 : 1
S_2 s_2, S_3 S_3, S_4 S_4	Colored	3 : 1
S_2 S_2, S_3 s_3, S_4 s_4	15 : 1	45 : 19
S_2 s_2, S_3 S_3, S_4 s_4	15 : 1	45 : 19
S_2 s_2, S_3 s_3, S_4 S_4	15 : 1	45 : 19

$S_2\ s_2, S_3\ s_3, S_4\ s_4$	54 : 10	162:94
$s_2\ s_2, S_3\ S_3, S_4\ S_4$	Colored	3 : 1
$s_2\ s_2, S_3\ s_3, S_4\ S_4$	3 : 1	9 : 7
$s_2\ s_2, S_3\ S_3, S_4\ s_4$	3 : 1	9 : 7
$s_2\ s_2, S_3\ s_3, S_4\ s_4$	9 : 7	27 : 37
$S_2\ S_2, s_3\ s_3, S_4\ S_4$	Colored	3 : 1
$S_2\ s_2, s_3\ s_3, S_4\ S_4$	3 : 1	9 : 7
$S_2\ S_2, s_3\ s_3, S_4\ s_4$	3 : 1	9 : 7
$S_2\ s_2, s_3\ s_3, S_4\ s_4$	9 : 7	27 : 37
$S_2\ S_2, S_3\ S_3, s_4\ s_4$	Colored	3 : 1
$S_2\ s_2, S_3\ S_3, s_4\ s_4$	3 : 1	9 : 7
$S_2\ S_2, S_3\ s_3, s_4\ s_4$	3 : 1	9 : 7
$S_2\ s_2, S_3\ s_3, s_4\ s_4$	9 : 7	27 : 37

This hypothesis may be tested in a number of ways. In the first place, the system of interaction outlined accounts for all the ratios obtained and recorded in Table 10. In addition, a ratio of 45 colored to 19 colorless scutellums is permitted, which closely approximates the 48:16 of a 3:1 ratio. The F_3 breeding behavior, presented in a later section, shows that certain progenies listed in Group 1 (3:1) of Table 10 properly belonged in the 45:19 category.

The methods that have been employed to check the hypothesis in greater detail are the breeding behavior of colored and colorless F_2 segregates and the identification of colored and colorless genotypes by appropriate intercrosses.

BEHAVIOR OF COLORED SCUTELLUMS IN THE F_3 GENERATION

The system of factor interaction previously outlined requires the existence of eight different ratios. These have been obtained from various crosses, and the F_3 breeding behavior of the colored segregates is presented in the following sections.

RATIOS OF 162 TO 94

An F_2 ratio of 162 colored to 94 colorless scutellums is expected when the F_1 is of the constitution $S_1\ s_1, S_2\ s_2, S_3\ s_3, S_4\ s_4$.

Colored segregates from ratios approximating this were planted and the progeny classified to determine their F_3 behavior. The eight ratio types listed in the factor-interaction diagram (p. 11) were obtained. These data are presented in Groups A to G of Table 11. It was so obviously impossible to separate 3:1 and 45:19 ratios in the absence of data on breeding behavior that this was not attempted.

In Group A are listed six progenies that bred true for colored scutellums.

In Group B are listed 13 progenies whose ratios approximate 3:1 or 45:19. The total number of kernels in these progenies is 2,248. The mean percentage of colorless individuals in this group is 24.8. The percentage expectancy on the basis of a 3:1 ratio is 25.0, and that on a basis of 45:19 is 29.7.

Group C is composed of four progenies whose segregations approximate 9 colored to 7 colorless scutellums. The calculated percentage of colorless scutellums for this ratio is 43.8. The observed percentage is 41.3.

Progenies whose ratios approximate 27 colored to 37 colorless scutellums are listed in Group D. Only two such progenies were obtained, both of which have negative deviations. The mean deviation is only 1.3 times its probable error, and therefore well within the limits of chance fluctuations from expectancy.

TABLE 11.—*Records of scutellum colors in 35 F_3 progenies of F_2 colored segregates of a 162 : 94 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_2	F_3	Colored	Colorless	Total		
A (1 : 0)	639-5	853-2	157	0	157		
		853-3	133	0	133		
		853-10	58	0	58		
	639-15	852-8	108	0	108		
		852-9	175	0	175		
		852-18	191	0	191		
Total			822	0	822		
B (3 : 1; 45 : 19)	639-5	853-5	100	35	135	25.9	
		853-6	135	44	179	24.6	
		853-14	112	35	147	23.8	
		853-15	77	21	98	21.4	
		853-17	50	14	64	21.9	
		853-19	76	25	101	24.8	
		853-20	164	65	229	28.4	
	639-15	852-5	180	66	246	26.8	
		852-6	207	70	277	25.3	
		852-11	179	62	241	25.7	
		852-13	133	34	167	20.4	
		852-14	108	42	150	28.0	
		852-15	169	45	214	21.6	
Total			1,690	558	2,248	24.8	
C (9 : 7)	639-5	853-1	20	15	35	42.9	0.2
		853-13	91	63	154	40.9	1.1
		853-16	113	83	196	42.3	.6
	639-15	852-4	52	33	85	38.8	1.4
Total			276	194	470	41.3	1.6
D (27 : 37)	639-5	853-9	51	62	113	54.9	1.0
	639-15	852-17	105	132	237	55.7	1.0
Total			156	194	350	55.4	1.3
E (15 : 1)	639-5	853-4	145	8	153	5.2	.7
		853-18	115	7	122	5.7	.4
	639-15	852-1	194	18	212	8.5	2.0
		852-7	45	3	48	6.3	0
Total			499	36	535	6.7	.7
F (54 : 10)	639-5	853-7	190	30	220	13.6	.9
		853-11	155	33	188	17.6	1.1
	639-15	852-2	162	23	185	12.4	1.8
Total			507	86	593	14.5	1.1
G (162 : 94)	639-5	853-8	77	34	111	30.6	1.9
		853-12	129	65	194	33.5	1.4
	639-15	852-16	188	88	276	31.9	2.5
Total			394	187	581	32.2	3.4

Group E is composed of progenies approximating 15 colored to 1 colorless scutellum. Of the four progenies, two have negative and two have positive deviations. The group deviation is positive, the deviation divided by probable error being 0.7.

Progenies having approximately 54 colored to 10 colorless scutellums are listed in Group F. The observed percentage of colorless scutellums for this ratio is 14.5, the theoretical expectancy being 15.6 per cent.

Group G comprises the three progenies having ratios approximating 162 colored to 94 colorless scutellums. All three progenies have negative deviations. The deviation divided by probable error is 3.4.

Within each of the above groups the agreement between observation and theory is satisfactory, with the exception of the last group (G). The agreement between the observed and calculated number of progenies in each group is shown in Table 12. The value for χ^2 is 12.27, giving a probability of only 0.06. Half of the total χ^2 value is obtained from the Group A deviation. A possible explanation for the excess in this group may be differential germination. Kernels that are homozygous for colored scutellums or heterozygous for one or two factor pairs can be classified as colored with little injury to the germ. With an increase in the number of heterozygous factor pairs, the scutellums are lighter colored and must be cut more deeply to insure correct classification.

TABLE 12.—*Comparison of observed and calculated number of progenies in groups shown in Table 11*

Items	Group							Total
	A	B	C	D	E	F	G	
Observed	6	13	4	2	4	3	3	35
Calculated	2.2	12.1	7.8	5.2	2.6	1.7	3.5	35.1
Difference	+3.8	+.9	−3.8	−3.2	+1.4	+1.3	−.5	−.1

$\chi^2 = 12.27$. $P = 0.06$

The F_3 behavior of colored segregates from the 162 : 94 ratios gave all of the ratios called for by the hypothesis. The agreement between the observed and calculated distribution of progenies, however, is poor.

RATIOS OF 54 TO 10

Colored scutellum kernels of F_2 ratios approximating 54 colored to 10 colorless were tested in F_3. Ratios of this type are expected when the F_1 is of the constitution S_1 s_1, S_2 s_2, S_3 s_3, S_4 s_4. Thirty-eight F_3 progenies were classified, the number of individuals totaling 6,774. These progenies are divided into five groups on the basis of the percentage of colorless scutellum individuals. The data are listed in Table 13.

Group A includes 10 progenies. Among 1,853 kernels were 8 with colorless scutellums. These were not tested further, but are probably due to accidental pollination by stray pollen grains from the dominant white strain.

In Group B, whose progenies approximate ratios of 3 colored to 1 colorless scutellum, the percentages of colorless scutellums range from 18.8 to 30.4. The mean percentage of colorless individuals for the group is 24.7, which is close to the expected 25 per cent.

Group C, made up of progenies segregating in ratios of 9 colored to 7 colorless scutellums, has an average percentage of colorless individuals of 39.9. The expected percentage for this ratio is 43.8. Five of the six progenies have negative deviations. The total deficiency of colorless scutellums is 39 individuals, giving a deviation divided by probable error of 3.7.

TABLE 13.—*Records of scutellum colors in 38 F_3 progenies of F_2 colored segregates of a 54:10 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_2	F_3	Colored	Colorless	Total		
A (1:0)	323-8	666- 2	235	2	237		
		666- 3	106	1	107		
		666- 7	326	0	326		
		666-11	165	2	167		
		666-14	267	1	268		
		666-17	166	0	166		
		666-19	194	0	194		
		666-21	129	0	129		
		666-24	106	2	108		
		666-26	151	0	151		
Total			1,845	8	1,853		
B (3:1)	323-8	666- 1	189	70	259	27.0	1.1
		666-10	138	39	177	22.0	1.3
		666-13	149	54	203	26.6	.8
		666-15	128	49	177	27.7	1.2
		666-18	147	34	181	18.8	2.9
		666-29	110	48	158	30.4	2.3
		666-31	126	33	159	20.8	1.8
		666-38	42	10	52	19.2	1.4
Total			1,029	337	1,366	24.7	.5
C (9:7)	323-8	666- 5	209	148	357	41.5	1.3
		666- 8	149	80	229	34.9	4.0
		666-25	148	112	260	43.1	.3
		666-27	54	41	95	43.2	.2
		666-34	65	34	99	34.3	2.8
		666-37	25	21	46	45.7	.4
Total			650	436	1,086	39.9	3.7
D (15:1)	323-8	666- 4	143	11	154	7.1	.7
		666- 6	197	9	206	4.4	1.7
		666-12	268	24	292	8.2	2.1
		666-16	249	22	271	8.1	1.9
		666-20	167	6	173	3.5	2.2
		666-22	236	7	243	2.9	3.2
		666-23	181	12	193	6.2	0
		666-29	81	4	85	4.7	.9
Total			1,522	95	1,617	5.9	.9
E (54:10)	323-8	666- 9	253	44	297	14.8	.6
		666-28	108	16	124	12.9	1.2
		666-30	143	21	164	12.8	1.5
		666-33	106	16	122	13.1	1.1
		666-35	61	9	70	12.9	.9
		666-36	64	11	75	14.7	.3
Total			735	117	852	13.7	2.3

Progenies whose segregations approximate 15 colored to 1 colorless scutellum comprise Group D. Five of the eight progenies in this group have negative deviations, the remaining three being positive. The cumulative deviation is very small, but negative, the deviation divided by probable error being 0.9.

Group E is made up of six progenies whose ratios approximate 54 colored to 10 colorless scutellums. There is a suggestion that deviations in this group are not random, as all are negative. The deviation divided by probable error, however, is 2.3, which is within the limits of random fluctuations.

It has been shown that the agreement between the theoretical and observed percentages of colorless scutellums within each group with one exception has been fair. A comparison of the number of progenies in each group with the calculated expectancy is shown in Table 14. The agreement is good, only one trial in four being expected to give a better fit.

TABLE 14.—*Comparison of observed and calculated number of progenies in groups shown in Table 13*

Items	Group					Total
	A	B	C	D	E	
Observed	10	8	6	8	6	38
Calculated	7	8.4	8.4	8.4	5.6	37.8
Difference	+3.0	−.4	−2.4	−.4	+.4	+.2

$\chi^2 = 2.05$. $P = 0.73$

RATIOS OF 45 TO 19

The data from 13 F_3 progenies grown from colored scutellum kernels of 45:19 ratios are listed in Table 15. These progenies are divided into four groups on the basis of their breeding behavior.

Group A consists of the true-breeding colored scutellum progenies. These three progenies have a total of 324 kernels. In one progeny a single colorless scutellum kernel was observed.

TABLE 15.—*Records of scutellum colors in 13 F_3 progenies of F_2 colored segregates of a 45:19 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_2	F_3	Colored	Colorless	Total		
A (1 : 0)	327-4	641-5	140	0	140		
		641-8	142	0	142		
		641-13	41	1	42		
Total			323	1	324		
B (3 : 1; 45 : 19)	327-4	641-1	190	63	253	24.9	
		641-2	189	36	225	16.0	
		641-3	170	63	233	27.0	
		641-4	181	25	206	12.1	
		641-9	137	32	169	18.9	
		641-10	102	18	120	15.0	
Total			969	237	1,206	19.6	
C (9 : 7)	327-4	641-7	85	87	172	50.6	2.8
D (15 : 1)	327-4	641-6	154	13	167	7.8	1.2
		641-11	112	10	122	8.2	1.4
		641-12	70	4	74	5.4	.4
Total			336	27	363	7.4	1.4

Group B comprises progenies approximating either 3:1 or 45:19 ratios. No attempt has been made to separate these progenies because of the obvious impossibility of doing so accurately except by breeding behavior.

A single progeny approximating a 9:7 ratio falls in Group C. In this progeny there is an excess of kernels belonging to the colorless scutellum class, the deviation divided by probable error being 2.8.

Group D includes those progenies having ratios of 15 colored to 1 colorless scutellum. Of the three progenies in this group, two have positive and one a negative deviation.

Considering all of the groups, the agreement between the number of progenies observed and expected on the basis of a 45:19 ratio is as shown in Table 16.

TABLE 16.—*Comparison of observed and calculated number of progenies in groups shown in Table 15*

Items	Group				Total
	A	B	C	D	
Observed	3	6	1	3	13
Calculated	2.0	7.5	2.3	1.2	13
Difference	+1.0	−1.5	−1.3	+1.8	0

$\chi^2=4.23$. $P=0.24$

A possible explanation of the large deviations occurring in certain of these F_3 progenies may be pollen-tube growth factors. Many of the progenies were segregating for sugary endosperm, and the deviations are greatest in these progenies. This suggests that the *Ga ga* factor pair (*11*) may be involved. Data were obtained on the linkage of S_1 s_1 and *Su su* in progenies homozygous for the gametophyte factor. The crossing over between these two factors was found to be about 37.6 per cent. The detailed data are presented in Table 17. If the S_1 locus is to the right of sugary, the gametophyte factor should have little influence on the colored to colorless segregations, as the map distance between the two genes would be approximately 60 units. However, if the S_1 locus is to the left of sugary, it would be only about 20 units from the gametophyte factor, with some 20 per cent of crossing over between S_1 and *Ga*.

In conformity with Mangelsdorf and Jones (*11*) it has been assumed that *Ga*-bearing gametes effect fertilization four times as often as gametes carrying *ga*. Linkage being in the coupling phase, the calculated percentage of colorless scutellums then would be 16.0. For the "low" progenies in group B of Table 15 the mean percentage of colorless scutellums is 15.4. Linkage being in the repulsion phase, the percentage of colorless scutellums would be 34.0. One progeny which might be classed as "high" had 27.0 per cent of colorless scutellums. The agreement is sufficiently close to suggest that the order of the genes may be S_1–*Ga*–*Su*, and that the action of *Ga ga* was a partial cause of the discrepancies.

TABLE 17.—*Records of scutellum color in five back-cross progenies of the cross (su S_1 × Su s_1) × su s_1*

Pedigree No.	Su		su		Percentage crossing over
	S_1	s_1	S_1	s_1	
1027–1 × 1026–1	40	57	58	26	36.5
1027–3 × 1026–1	27	41	49	26	37.1
1027–5 × 1026–1	38	61	56	35	38.4
1027–9 × 1026–1	26	43	47	31	38.8
1027–10 × 1026–1	10	19	19	12	36.7
Total	141	221	229	130	37.6

The situation is complicated further by the fact that some of the progenies in this group probably belonged in the 45:19 rather than in the 3:1 category.

RATIOS OF 27 TO 37

Seventeen F_3 progenies of colored segregates from 27:37 ratios were classified. The data are presented in Table 18. One of the 17 progenies bred true for colored scutellums.

Group B is made up of progenies having approximately 25 per cent of colorless scutellums, the mean percentage of colorless scutellums being 25.1.

In Group C half of the progenies have positive deviations on the basis of a 9:7 segregation, the remaining half being negative. The deviation for the group is negative, amounting to 12 individuals.

The three progenies in Group D approximate the 57.8 per cent of colorless scutellums expected with a 27:37 ratio. All the progenies have negative deviations. The deviation divided by probable error for the group is 2.4.

The agreement between the observed and calculated number of progenies for each group is shown in Table 19. The fit is reasonably good.

TABLE 18.—*Records of scutellum color in 17 F_3 progenies of F_2 colored segregates of a 27:37 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_2	F_3	Colored	Colorless	Total		
A (1:0)	639–10	855–11	158	0	158		
B (3:1)	639–10	855–1	164	59	223	26.5	0.7
		855–2	148	48	196	24.5	.2
		855–5	210	76	286	26.6	.9
		855–15	60	18	78	23.1	.6
		855–16	140	41	181	22.7	1.1
Total			722	242	964	25.1	.1
C (9:7)	639–10	855–3	134	85	219	38.8	2.2
		855–4	116	70	186	37.6	2.5
		855–8	99	76	175	43.4	.1
		855–9	122	88	210	41.9	.8
		855–13	118	101	219	46.1	1.0
		855–14	120	97	217	44.7	.4
		855–17	80	67	147	45.6	.7
		855–19	141	118	259	45.6	.9
Total			930	702	1,632	43.0	.9
D (27:37)	639–10	855–7	79	97	176	55.1	1.1
		855–10	50	61	111	55.0	.9
		855–12	129	151	280	53.9	2.0
Total			258	309	567	54.5	2.4

TABLE 19.—*Comparison of observed and calculated number of progenies in groups shown in Table 18*

Items	Group				Total
	A	B	C	D	
Observed	1	5	8	3	17
Calculated	.6	3.8	7.6	5	17
Difference	+.4	+1.2	+.4	−2	0

$\chi^2 = 1.47$. $P = 0.69$

RATIOS OF 9 TO 7

Colored scutellum kernels from 9:7 F_2 ratios were used in a test in which 28 F_3 progenies having a total of 5,379 individuals were classified. The detailed data are presented in Table 20. As expected, the progenies fall into three distinct groups. Group A contains all the true-breeding forms, Group B those progenies segregating in ratios of 3 colored scutellums to 1 colorless, and Group C the progenies approximating a ratio of 9:7.

Among the 662 individuals in Group A are 5 colorless scutellums. It is believed that these are due to foreign pollen.

The 11 progenies in Group B have percentages of colorless scutellums ranging from 21.7 to 29.1, the expected percentage being 25.0. Five of the 11 progenies have positive deviations, the cumulative deviation likewise being positive. The deviation divided by probable error is low, the value being 0.3.

Group C contains 13 progenies whose percentages of colorless individuals range from 38.5 to 47.3. The cumulative deviation is negative, the deviation divided by probable error being 3.2.

A comparison between the observed number of progenies in each group and the theoretical expectancy is shown in Table 21. The fit here is unusually close, χ^2 being less than 1.0.

TABLE 20.—*Records of scutellum colors in 28 F_3 progenies of F_2 colored segregates of a 9:7 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_2	F	Colored	Colorless	Total		
A (1:0)	327–7	640–3	188	0	188		
		640–5	143	5	148		
		640–19	208	0	208		
		640–22	118	0	118		
Total			657	5	662		
B (3:1)	327–7	640–2	176	62	238	26.1	0.6
		640–4	160	52	212	24.5	.2
		640–6	156	60	216	27.8	1.4
		640–7	155	50	205	24.4	.3
		640–8	181	57	238	23.9	.6
		640–9	186	68	254	26.8	1.0
		640–10	163	67	230	29.1	2.1
		640–11	185	52	237	21.9	1.6
		640–15	158	55	213	25.8	.4
		640–16	159	44	203	21.7	1.6
		640–27	28	8	36	22.2	.6
Total			1,707	575	2,282	25.2	.3

TABLE 20.—*Records of scutellum colors in 28 F_3 progenies of F_2 colored segregates of a 9:7 ratio*—Continued

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_2	F_3	Colored	Colorless	Total		
C (9:7)	327-7	640-1	130	99	229	43.2	.2
		640-12	119	80	199	40.2	1.5
		640-13	116	89	205	43.4	.1
		640-14	151	95	246	38.6	2.4
		640-17	144	96	240	40.0	1.7
		640-18	126	84	210	40.0	1.6
		640-20	150	97	247	39.3	2.1
		640-21	101	82	183	44.8	.4
		640-23	83	58	141	41.1	.9
		640-24	87	69	156	44.2	.2
		640-25	60	41	101	40.6	.9
		640-26	67	42	109	38.5	1.6
		640-28	89	80	169	47.3	1.4
Total			1,423	1,012	2,435	41.6	3.2

TABLE 21.—*Comparison of observed and calculated number of progenies in groups shown in Table 20*

Items	Group			Total
	A	B	C	
Observed	4	11	13	28
Calculated	3.1	12.4	12.4	27.9
Difference	+.9	−1.4	+.6	+.1

$\chi^2=0.45$. $P=0.80$

The values for P when χ^2 is less than 1 have been taken from Fisher's table (*4*).

RATIOS OF 15 TO 1

Nineteen F_3 progenies were grown from colored scutellum segregates of ratios of 15 colored to 1 colorless. The detailed data are presented in Table 22. The data are divided into three groups on the basis of their F_3 segregations. Group A contains the true-breeding colored scutellum progenies. Among 1,258 individuals in nine progenies no colorless scutellums were observed.

Progenies whose segregations approximate 3 colored to 1 colorless scutellum are included in Group B. In this group the cumulative deviation is negative, the deviation divided by probable error being 1.3.

Group C contains six progenies whose segregations approximate 15 colored to 1 colorless scutellum. The total deviation is negative, the observed percentage of colorless individuals being 5.3, whereas 6.3 per cent were expected. The deviation divided by probable error is 1.7 for the group.

A comparison between the observed and calculated distribution of progenies is shown in Table 23.

TABLE 22.—*Records of scutellum colors in 19 F_3 progenies of F_2 colored segregates of a 15:1 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_2	F_3	Colored	Colorless	Total		
A (1:0)	328-3	643-1	217	0	217		
		643-2	192	0	192		
		643-3	147	0	147		
		643-5	157	0	157		
		643-7	167	0	167		
		643-10	172	0	172		
		643-15	123	0	123		
		643-17	49	0	49		
		643-19	34	0	34		
Total			1,258	0	1,258		
B (3:1)	328-3	643-8	129	49	178	27.5	1.2
		643-12	134	35	169	20.7	1.9
		643-16	107	32	139	23.0	.8
		643-18	56	14	70	20.0	1.4
Total			426	130	556	23.4	1.3
C (15:1)	328-3	643-4	161	6	167	3.6	2.1
		643-6	138	11	149	7.4	.8
		643-7	137	5	142	3.5	2.0
		643-11	116	7	123	5.7	.4
		643-13	128	8	136	5.9	.3
		643-14	108	7	115	6.1	.1
Total			788	44	832	5.3	1.7

TABLE 23.—*Comparison of observed and calculated number of progenies in groups shown in Table 22*

Items	Group			Total
	A	B	C	
Observed	9	4	6	19
Calculated	8.9	5.1	5.1	19.1
Difference	+.1	−1.1	+.9	−.1

$\chi^2=0.40$. $P=0.82$

RATIOS OF 3 TO 1

The data on the five F_3 progenies grown from colored scutellum segregates of 3:1 F_2 ratios are given in Table 24. On the basis of monohybrid segregation, the F_3 population should consist of segregating and true-breeding progenies in the ratio of 2:1. With five progenies the calculated ratio becomes 3.3:1.7, whereas the observed ratio was 4:1. All the ratios in the segregating group have approximately 25 per cent of colorless scutellums.

TABLE 24.—*Records of scutellum color in five F_3 progenies of F_2 colored segregates of a 3:1 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_2	F_3	Colored	Colorless	Total		
A (1:0)	781-1	859-2	112	0	112		
B (3:1)	781-1	859-1	85	30	115	26.1	0.4
		859-3	128	49	177	27.7	1.2
		859-4	68	19	87	21.8	1.0
		859-7	129	42	171	24.6	.2
Total			410	140	550	25.5	.4

The behavior of all the F_3 progenies grown from F_2 colored scutellum segregates has been in reasonable accord with the proposed hypothesis. In every case the expected ratio types have been obtained, and in most cases the agreement between observation and theory has been good. The results of other tests of the hypothesis are presented in the following sections.

BEHAVIOR OF COLORLESS SCUTELLUMS IN THE F_3 GENERATION

Colorless scutellum segregates of progenies representing each of the six groups in Table 10 were tested in F_3. The detailed data are given in Table 25.

The data presented in this table, totaling 8,054 individuals, are in accord with the hypothesis, as all colorless scutellum segregates breed true for this condition. In each group a few colored scutellum individuals were obtained. In every instance these exceptions represent a small percentage of the population and are believed to be due to accidental pollination. Again no attempt has been made to separate individuals from 3:1 and from 45:19 ratios.

TABLE 25.—*Records of scutellum color in 42 F_3 progenies of colorless F_2 segregates of groups 1 to 6 of Table 10*

Group and ratio of preceding generation	Pedigree No.		Number of individuals	
	F_2	F_3	Colored	Colorless
1 (3 : 1)	170–2	352–2	2	26
	178–5	355–10	0	191
	176–5	356–1	0	125
		356–6	0	61
	242–9	357–9	0	30
	196–6	361–2	0	100
		361–7	0	145
	242–13	365–3	2	300
	242–9	429–1	4	238
Total			8	1,216
2 (9 : 7)	327–7	649–1	8	270
		649–2	1	238
		649–3	0	239
		649–4	0	216
		649–5	1	99
		649–6	0	203
		649–7	2	215
Total			12	1,480
3 (27 : 37)	327–6	648–1	3	87
		648–2	0	192
		648–3	0	283
		648–4	6	250
		648–5	3	311
		648–6	0	312
		648–7	1	231
		648–8	1	261
		648–9	0	285
Total			14	2,212
4 (15 : 1)	320–10	655–1	0	187
		655–2	0	132
		655–3	2	211
		655–4	1	198
		655–6	0	156
		655–7	0	101
		655–8	0	83
Total			3	1,068

TABLE 25.—*Records of scutellum color in 42 F_3 progenies of colorless F_2 segregates of groups 1 to 6 of Table 10*—Continued

Group and ratio of preceding generation	Pedigree No.		Number of individuals	
	F_2	F_3	Colored	Colorless
5 (54 : 10)	320–9	651–1	0	171
		651–2	0	50
		651–3	7	118
		651–4	1	213
		651–5	0	137
		651–6	0	164
		651–9	1	198
Total			9	1,051
6 (162 : 94)	322–13	647–3	0	350
		647–4	0	275
		647–5	0	356
Total			0	981

The hypothesis under test requires that colorless scutellum segregates from 3 : 1 and 15 : 1 ratios should be of four types. These can be used as scutellum testers to determine the genotypic constitution of unknown whites. These theoretical types are given below prior to the proof of their existence.

s_1 tester ..... s_1 S_2 S_3 S_4
s_2, s_3 tester ..... S_1 s_2 s_3 S_4
s_3, s_4 tester ..... S_1 S_2 s_3 s_4
s_2, s_4 tester ..... S_1 s_2 S_3 s_4

Each of these testers should produce only colorless scutellums when self-pollinated or when crossed with strains having a similar genetic constitution. In addition, the F_1 cross between any two different testers should produce only colored scutellums.

Evidence that four testers exist, and that their behavior is as outlined above, is presented in Table 26. Selfed progenies of each of the testers bred true for colorless scutellums, the few colored scutellum kernels presumably being outcrosses. F_1 crosses of one tester by any different tester have all colored scuttelums. The numbers are not large, but they are consistent and in accord with the hypothesis.

TABLE 26.—*Records of scutellum colors in F_1 of selfed and intercrossed scutellum testers*

Pedigree No.	Testers and crosses	Number of individuals		
		Colored	Colorless	Total
822–5	s_1	3	207	210
821–4	do	0	264	264
824–14	do	14	230	244
Total		17	701	718
820–2	s_2	0	180	180
820–11 × 2	do	0	253	253
Total		0	433	433
823–2	s_3	0	195	195
823–6	do	1	113	114
831–9	do	2	81	83
Total		3	389	392

TABLE 26.—*Record of scutellum colors in F_1 of selfed and intercrossed scutellum testers*—Continued

Pedigree No.	Testers and crosses	Number of individuals		
		Colored	Colorless	Total
832-13	s_4	4	187	191
821-7 × 820-2	$s_1 \times s_2$	17	0	17
822-11 × 820-2		46	0	46
822-9 × 820-2		247	0	247
824-3 × 820-2		29	0	29
Total		339	0	339
822-8 × 823-4	$s_1 \times s_3$	3	0	3
831-11 × 822-5	do	2	0	2
822-15 × 819-2	do	62	0	62
822-1 × 819-2	do	108	13	121
Total		175	13	188
822-4 × 832-11	$s_1 \times s_4$	88	5	93
832-9 × 822-5	do	22	0	22
Total		110	5	115
823-3 × 820-2	$s_2 \times s_3$	2	0	2
831-7 × 820-2	do	7	0	7
819-2 × 820-1	do	59	4	63
Total		68	4	72
832-1 × 820-2	$s_2 \times s_4$	27	0	27
820-7 × 832-11	do	83	0	83
Total		110	0	110
831-10 × 832-11	$s_3 \times s_4$	219	1	220
832-6 × 823-4		158	2	160
Total		377	3	380

Crosses between the various testers would be expected to show two types of breeding behavior in the F_2 generation. Crosses involving s_1 and any two factors of the series s_2, s_3, and s_4 will exhibit F_2 ratios of 45 colored to 19 colorless scutellums. Crosses of testers involving only members of the s_2, s_3, and s_4 series should give an F_2 ratio of 9 colored to 7 colorless scutellums. The data for such F_2 crosses are presented in Table 27 and are in close accord with expectations.

In the early attempts to isolate testers, success was only partial. Colorless scutellum kernels from supposedly 3:1 ratios behaved very erratically in crosses. This unexpected behavior was easily explained after proper distinction had been made between 3:1 and 45:19 ratios. The nonconforming whites had been obtained from 45:19 ratios and were actually recessive for 1, 2, or 3 factor pairs.

No attempt has been made to prove the existence of all the expected genotypes of colorless scutellums from any single cross or group of crosses.

HOMOZYGOUS COLORED × MULTIPLE RECESSIVE COLORLESS SCUTELLUMS

Colored scutellum strains homozygous for all four factors, S_1, S_2, S_3, and S_4, when crossed with the multiple recessive colorless stocks should produce F_2 ratios of approximately 162 colored to 94 colorless scutellums. On the other hand, colored scutellum strains

homozygous for S_1 S_1 and two of the other three factor pairs should produce 27:37 ratios in F_2 when crossed with multiple recessive colorless stocks. Both of these ratios were obtained, as shown by the data in Table 28, proving the existence of true-breeding colored scutellums of at least two genotypes.

TABLE 27.—*Records of scutellum color in 18 F_2 progenies of crosses of colorless scutellum testers*

Tester and pedigree No.	Number of individuals			Percentage colorless	Dev. / P. E.
	Colored	Colorless	Total		
$s_1 \times s_2$:					
6696–2	110	40	150	26.7	1.2
6697–3	39	18	57	31.6	.5
Total	149	58	207	28.0	.8
$s_1 \times s_4$:					
6700–1	308	131	439	29.8	1.0
6700–3	162	35	197	17.8	5.4
6700–4	104	37	141	26.2	1.3
6700–5	159	60	219	27.4	1.1
6701–2	75	32	107	29.9	.1
6701–4	134	59	193	30.6	.4
Total	942	354	1,296	27.3	2.8
$s_2 \times s_3$:					
6702–2	62	41	103	39.8	1.2
$s_2 \times s_4$:					
6704–2	74	51	125	40.8	1.0
6704–3	219	160	379	42.2	.9
6704–5	80	62	142	43.7	0
Total	373	273	646	42.3	1.1
$s_3 \times s_4$:					
6705–1	49	29	78	37.2	1.7
6705–2	85	76	161	47.2	1.3
6705–3	72	58	130	44.6	.3
6705–4	74	56	130	43.1	.2
6706–1	65	48	113	42.5	.4
6706–5	26	20	46	43.5	.1
Total	371	287	658	43.6	.1

TABLE 28.—*Records of scutellum colors in 11 F_2 progenies of crosses of homozygous colored × multiple recessive colorless scutellum strains*

Group and ratio	Pedigree No.	Number of individuals			Percentage colorless	Dev. / P. E.
		Colored	Colorless	Total		
A (162:94)	866–3	113	60	173	34.7	0.9
	866–4	75	39	114	34.2	1.0
	866–8	136	68	204	33.3	1.6
	867–2	86	57	143	39.9	1.1
	867–7	101	58	159	36.5	.1
	868–1	78	29	107	27.1	3.1
Total		589	311	900	34.6	2.0
B (27:37)	862–5	114	126	240	52.5	2.5
	862–4	81	98	179	54.7	1.3
	863–3	79	100	179	55.9	.8
	870–1	101	120	221	54.3	1.5
	870–5	124	148	272	54.4	1.7
Total		499	592	1,091	54.3	3.5

INTERCROSSES OF HOMOZYGOUS COLORED SCUTELLUM STRAINS

Colored scutellum strains of the constitution S_1 S_1, S_2 S_2, S_3 S_3, S_4 S_4, when crossed with any other true-breeding colored scutellum genotype, should produce only colored scutellums in subsequent generations. Data from one such cross are presented in Table 29.

Crosses between colored scutellum strains homozygous for three factors but unlike in genotype should give ratios of 15 colored to 1 colorless scutellum in F_2. Data from one cross of this kind are presented in Table 30. The data prove the existence of two different genotypes of colored scutellum strains, each homozygous for three factor pairs. The hypothesis calls for three such genotypes. The occurrence of the third has not been demonstrated. The data which have been presented, however, give sufficiently conclusive proof of the existence of three of the four required types of homozygous colored scutellum strains.

TABLE 29.—*Records of scutellum color in 10 F_2 progenies of crosses of colored × colored scutellum strains*

Pedigree No.	Number of individuals			Pedigree No.	Number of individuals		
	Colored	Colorless	Total		Colored	Colorless	Total
349–1	203	0	203	349–7	209	0	209
349–2	179	5	184	349–8	197	0	197
349–3	106	0	106	349–9	154	2	156
349–4 × 349–2	70	0	70	349–10	222	5	227
349–5	250	0	250				
349–6	242	8	250	Total	1,832	20	1,852

TABLE 30.—*Records of scutellum colors in five F_2 progenies of crosses of colored × colored scutellum strains*

Pedigree No.	Number of individuals			Percentage colorless	Dev. / P. E.
	Colored	Colorless	Total		
348–1	227	14	241	5.8	0.4
348–2	235	13	248	5.2	1.0
348–6	246	15	261	5.7	.5
348–7	264	10	274	3.6	2.6
348–9	236	13	249	5.2	1.0
Total	1,208	65	1,273	5.1	2.5

AGREEMENT WITH HYPOTHESIS

The data for the purple and red scutellum series have been in agreement with the proposed hypothesis in each of the several ways that it was tested. The behavior of colored segregates from the different ratios was in accord with expectancy. Colorless segregates bred true for this condition. Intercrosses between colorless scutellum strain from 3:1 and 15:1 ratios furnished evidence for the existence of four different colorless testers. Colored scutellum strains crossed with a multiple recessive colorless strain produced the expected F_2 results. Appropriate intercrosses demonstrated the existence of three of the four different homozygous colored scutellum

strains required by the hypothesis. There is close agreement between expectations under the hypothesis and all the observed facts. This seems to prove conclusively the assumption of at least four factors interacting as described, determining the purple-red coloration of the scutellum.

DOMINANT WHITE SCUTELLUMS

Through the kindness of I. F. Phipps, many of his cultures were examined for possible scutellum color segregation. In his culture 1561–A an ear was found which segregated in a ratio of approximately 9 colored to 55 colorless scutellums. Such a ratio would be expected from the interaction of a dominant white scutellum factor with factors of the purple and red series which otherwise would have resulted in a 9 : 7 ratio.

A dominant white scutellum strain was isolated from the progeny of this ear. Repeated tests have shown this scutellum factor, S_5 s_5, to be completely dominant in either the homozygous or the heterozygous condition. Unlike the *I i* factor pair, it has no effect on aleurone coloration.

Colorless scutellum seeds from this original ear were tested in the next generation. The results of this test are presented in Table 31. The 15 progenies can be divided into four groups.

TABLE 31.—*Records of scutellum color in 15 F_3 progenies of F_2 colorless segregates of a 9 : 55 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_2	F_3	Colored	Colorless	Total		
A (0 : 1)	P1561A–1	380–3	0	196	196		
		380–4	0	117	117		
		380–7	0	329	329		
		380–13	0	328	328		
		380–14	0	215	215		
		380–10	0	98	98		
		672–2	0	291	291		
		672–3	0	170	170		
Total			0	1,744	1,744		
B (1 : 3)	P1561A–1	380–11	46	156	202	77.2	1.1
		380–15	59	185	244	75.8	.4
Total			105	341	446	76.5	1.1
C (3 : 13)	P1561A–1	380–5	17	75	92	81.5	.1
		380–9	31	174	205	84.9	2.0
Total			48	249	297	83.8	1.7
D (9 : 55)	P1561A–1	380–8	18	141	159	88.7	1.5
		380–12	19	189	208	90.9	3.0
		672–1	21	118	139	84.9	.5
Total			58	448	506	88.5	2.5

Group A, totaling eight progenies, bred true for colorless scutellums. This group is composed of different types of whites. Some are white due to the action of the dominant scutellum factor; others are white because of the recessive condition of one or more of the necessary factors of the purple and red series. To identify these

different whites, all plants that were selfed were also used as pollen parents on colored scutellum strains. This will differentiate three sorts of whites, namely, homozygous dominant, heterozygous, and recessive. The results of these crosses are shown in Table 32. The three types of whites mentioned above should occur in the ratio of 16:32:7, or, for eight individuals, 2.3:4.7:1.0. The observed ratio was 2:5:1, an excellent fit in spite of the small number of progenies.

Group B (Table 31) contains two progenies approximating 1:3 ratios. In both progenies the deviations are small and positive.

The two progenies of Group C approximated ratios of 3 colored to 13 colorless scutellums. The fit is fair, the deviation divided by probable error being 1.7.

Group D consists of three progenies whose segregations approximate a 9:55 ratio. In two of the three progenies there is a deficiency of colored scutellums. For the three progenies the deviation divided by probable error is 2.5. This is a poor fit, but values of this magnitude are to be expected occasionally.

TABLE 32.—*Records of scutellum color in crosses of individuals of group A of Table 31 × colored scutellum strains*

Tester and pedigree No.	Number of individuals		
	Colored	Colorless	Total
S_5 S_5:			
B26-6 × 380-14	0	80	80
678-4 × 672-2	0	134	134
S_5 s_5:			
459-4 × 380-3	126	132	258
459-7 × 380-4	88	76	164
459-8 × 380-10	109	115	224
459-11 × 380-13	28	31	59
678-6 × 672-3	142	137	279
s_5 s_5:			
459-2 × 380-7	213	0	213

A comparison of the observed number of progenies in each group and the calculated expectancy is given in Table 33. When the small number of progenies is taken into consideration, the fit is fair.

TABLE 33.—*Comparison of observed and calculated number of progenies in groups shown in Table 31*

Items	Group				Total
	A	B	C	D	
Observed	8	2	2	3	15
Calculated	10.1	0.5	2.2	2.2	15
Difference	−2.1	+1.5	−.2	+.8	0

$\chi^2 = 5.25$. $P = 0.16$

Table 34 presents the detailed records of 20 F_4 progenies grown from colorless scutellum kernels from an F_3 ear segregating in the ratio of 3 colored to 13 colorless scutellums. In each group the

individual progeny records accord well with expectations. The comparison between the observed and expected number of progenies in each group is given in Table 35.

TABLE 34.—*Records of scutellum color in 20 F_4 progenies of F_3 colorless segregates of a 3:13 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_3	F_4	Colored	Colorless	Total		
A (0:1)	380–5	645–1	0	450	450		
		645–2	0	529	529		
		645–8	0	182	182		
		645–9	0	256	256		
		645–10	0	249	249		
		645–12	0	207	207		
		645–13	0	165	165		
		645–15	0	208	208		
		645–19	0	68	68		
		645–22	0	90	90		
		645–23	0	70	70		
Total			0	2,474	2,474		
B (1:3)	380–5	645–5	74	249	323	77.1	1.3
		645–6	49	143	192	74.5	.2
		645–7	85	232	317	73.2	1.1
		645–17	51	175	226	77.4	1.3
Total			259	799	1,058	75.5	.6
C (3:13)	380–5	645–1	64	259	323	80.2	.7
		645–3	58	265	323	82.0	.5
		645–11	55	226	281	80.4	.5
		645–14	79	292	371	78.7	1.9
		645–18	16	89	105	84.8	1.4
Total			272	1,131	1,403	80.6	.9

TABLE 35.—*Comparison of observed and calculated number of progenies in groups shown in Table 34*

Items	Group			Total
	A	B	C	
Observed	11	4	5	20
Calculated	10.8	3.1	6.2	20.1
Difference	+.2	+.9	−1.2	−.1

$\chi^2=0.49$. $P=0.78$

Records of scutellum color for 13 F_4 progenies, grown from F_3 colorless scutellum kernels from ears segregating in a 1:3 ratio, are shown in Table 36. The first group contains those progenies breeding true for colorless scutellums. The second group includes all progenies approximating a 1:3 segregation. The observed ratio of homozygous to heterozygous forms is 4:9. The calculated ratio for this number of progenies is 4.3:8.7. The fit is as nearly perfect as possible with this number of progenies.

Progenies heterozygous for dominant white and for duplicate factors of the purple and red scutellum series were obtained by appropriate crosses. The calculated F_2 ratio for such crosses is 15:49. This is a close approximation to the 1:3 ratio expected when only

the dominant white factor is involved. In the latter case the calculated percentage of colored scutellum kernels is 25.0, whereas for a 15:49 ratio it is 23.4. Random deviations from these theoretical expectancies would overlap to such a degree that separation on the basis of F_2 counts would be impossible. For this reason F_3 behavior has been used as proof for the existence of this type of ratio.

Table 37 contains the records for 11 F_3 progenies grown from colorless scutellum seeds from a 15:49 F_2 ratio. The data are listed in three groups on the basis of their percentages of colorless scutellums. Group A contains those progenies having all colorless scutellums. Group B is made up of progenies approximating a 3:13 ratio. Each of the three progenies in this group shows an excess of colorless scutellums. The cumulative excess amounts to 17 individuals. The deviation divided by probable error is 2.4, which is not a close fit.

TABLE 36.—*Records of scutellum colors in 13 F_4 progenies of F_3 colorless segregates of a 1:3 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_3	F_4	Colored	Colorless	Total		
A (0:1)	380-11	659-5	0	126	126		
		659-8	0	108	108		
		659-11	0	183	183		
		659-13	0	52	52		
Total			0	469	469		
B (1:3)	380-11	659-1	78	218	296	73.6	0.8
		659-2	135	388	523	74.2	.6
		659-3	88	290	378	76.7	1.1
		659-4	38	133	171	77.8	1.2
		659-6	62	160	222	72.1	1.5
		659-7	36	108	144	75.0	.0
		659-9	44	129	173	74.6	.2
		659-10	56	138	194	71.1	1.8
		659-12	10	26	36	72.2	.6
Total			547	1,590	2,137	74.4	1.0

Group C is made up of progenies having approximately 75 per cent of colorless scutellums. No attempt has been made to separate the 1:3 and 15:49 ratios. The percentage of colorless individuals for this group is intermediate between the theoretical expectancies for these ratios. In view of the small numbers, however, this point should not be stressed.

The agreement between the observed distribution of progenies and the theoretical expectancies on the basis of a 15:49 F_2 ratio is given in Table 38.

TABLE 37.—*Records of scutellum color in 11 F_3 progenies of F_2 colorless segregates of a 15:49 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_2	F_3	Colored	Colorless	Total		
A (0:1)	P2804-2	722-1	0	148	148		
		722-4	0	197	197		
		722-5	0	126	126		
		722-9	0	109	109		
		722-11	0	54	54		
Total			0	634	634		
B (3:13)	P2804-2	722-2	50	235	285	82.5	0.8
		722-7	33	180	213	84.5	1.8
		722-8	30	165	195	84.6	1.8
Total			113	580	693	83.7	2.4
C (1:3; 15:49)	P2804-2	722-3	57	165	222	74.3	
		722-6	58	157	215	73.0	
		722-10	24	78	102	76.5	
Total			139	400	539	74.2	

TABLE 38.—*Comparison of observed and calculated number of progenies in groups shown in Table 37*

Items	Group			Total
	A	B	C	
Observed	5	3	3	11
Calculated	4.3	4.9	1.8	11
Difference	+.7	−1.9	+1.2	0

$\chi^2 = 1.65$. $P = 0.45$

Additional proof for the existence of factors that interact with the S_5 s_5 factor pair to produce F_2 ratios of 15 colored to 49 colorless scutellums is given in Table 39. Colored scutellum kernels from 15:49 F_2 ratios were planted to determine the breeding behavior of their progeny. On the basis of a 15:49 F_2 ratio the colored segregates should show three types of behavior in the following generation, namely, true breeding and segregating in ratios of 3:1 and 15:1. In accordance with theory, observation revealed these three types. In the two segregating groups the percentages of colorless individuals are in close accord with expectancy. The comparison between the observed number of progenies in each group and the theoretical expectancy is given in Table 40.

TABLE 39.—*Records of scutellum color in eight F_3 progenies of F_2 colored segregates of a 15:49 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage colorless	Dev. / P. E.
	F_2	F_3	Colored	Colorless	Total		
A (1:0)	P2804-2	721-1	304	0	304		
		721-5	287	0	287		
		721-6	193	0	193		
		721-7	176	0	176		
Total			960	0	960		
B (3:1)	P2804-2	721-2	194	53	247	21.5	1.9
		721-8	132	49	181	27.1	1.0
Total			326	102	428	23.8	.8
C (15:1)	P2804-2	721-3	214	17	231	7.4	1.0
		721-4	164	9	173	5.2	.8
Total			378	26	404	6.4	.2

TABLE 40.—*Comparison of observed and calculated number of progenies in groups shown in Table 39*

Items	Group			Total
	A	B	C	
Observed	4	2	2	8
Expected	3.7	2.1	2.1	7.9
Difference	+.3	−.1	−.1	.1

$\chi^2 = 0.03$. $P = 0.98$

Data to be presented later indicate that the dominant action of the S_5 gene is specific for members of the S_1, S_2, S_3, and S_4 series, having no influence on orange (so_1 so_2) or yellow (sy) segregations.

ORANGE SCUTELLUMS

Orange scutellums were first observed by I. F. Phipps among his cultures in 1927. These were turned over to the writer for further study. All the data dealing with this color type were obtained from progenies tracing back to this original source.

Orange scutellum color develops only in the presence of the recessive allelomorphs of the factor pairs So_1 so_1 and So_2 so_2. Orange scutellum kernels produce progeny breeding true for this condition, as evidenced by the data in Table 41. Among 2,689 kernels, all except 5 have orange scutellums. These 5 probably were due to stray pollen, though this was not proved.

TABLE 41.—*Records of scutellum color in nine F_3 progenies of F_2 orange scutellum segregates*

Pedigree No.		Number of individuals		
F_2	F_3	White	Orange	Total
P2286-B-5	727-1	0	287	287
	727-7	0	254	254
	727-12	0	313	313
	727-14	0	418	418
	727-15	2	379	381
P2641-2	652A-1	0	177	177
	652A-3	1	211	212
	652A-5	2	389	391
	652A-6	0	256	256
Total		5	2,684	2,689

The records for scutellum color segregation for the original ears from Doctor Phipps's cultures are presented in Table 42. The first group includes the progenies whose ratios approximate 3:1. The fit is good, the deviation divided by probable error being only 0.4. The second group is made up of the progenies segregating in 15:1 ratios. The fit is reasonably good.

White scutellum segregates from 15 :1 F_2 ratios were planted to serve as the basis for a study of F_3 breeding behavior. The detailed data of the 22 progenies obtained are presented in Table 43. These progenies fall into three groups as expected. Group A contains the true-breeding whites. The nine progenies in this group have a total of 1,813 colorless scutellum kernels. Group B is made up of the progenies segregating in 3:1 ratios. Positive and negative deviations occur with equal frequency. The deviation for the group, however, is negative, the observed percentage of recessives being 23.5. Group C is composed of the progenies segregating in ratios of 15 colorless to 1 orange scutellum. The deviation divided by probable error for the group is 1.4. The agreement between the observed and expected number of progenies in each group is given in Table 44.

TABLE 42.—*Records of scutellum color in seven progenies segregating orange and white scutellums*

Group and ratio	Pedigree No.	Number of individuals			Percentage orange	Dev./P. E.
		White	Orange	Total		
A (3 : 1)	P2644-1-A	27	8	35	22.9	0.4
	P2286-A-2	111	40	151	26.5	.6
	P2286-B-5	103	35	138	25.4	.1
Total		241	83	324	25.6	.4
B (15 : 1)	P2640-1	40	4	44	9.1	1.2
	P2641-2	62	3	65	4.6	.8
	P2645-7	84	6	90	6.7	.2
	P2645-5x6	72	3	75	4.0	1.2
Total		258	16	274	5.8	.4

TABLE 43.—*Records of scutellum color in 22 F_3 progenies of F_2 white segregates of a 15:1 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage orange	Dev. / P. E.
	F_2	F_3	White	Orange	Total		
A (1:0)	P2641–2	652–2	247	0	247		
		652–3	255	0	255		
		652–4	323	0	323		
		652–9	290	0	290		
		652–11	162	0	162		
		652–15	227	0	227		
		652–17	112	0	112		
		652–18	160	0	160		
		652–21	37	0	37		
Total			1,813	0	1,813		
B (3:1)	P2641–2	652–7	230	88	318	27.7	1.6
		652–10	261	58	319	18.2	4.2
		652–16	62	16	78	20.5	1.4
		652–19	132	54	186	29.0	1.9
		652–20	88	19	107	17.8	2.6
		652–22	25	10	35	28.6	.7
Total			798	245	1,043	23.5	1.7
C (15:1)	P2641–2	652–1	307	18	325	5.5	.8
		652–5	299	14	313	4.5	1.9
		652–6	320	19	339	5.6	.7
		652–8	317	26	343	7.6	1.5
		652–12	189	9	198	4.5	1.5
		652–13	67	6	73	8.2	1.0
		652–14	56	2	58	3.4	1.3
Total			1,555	94	1,649	5.7	1.4

TABLE 44.—*Comparison of observed and calculated number of progenies in groups shown in Table 43*

Items	Group			Total
	A	B	C	
Observed	9	6	7	22
Calculated	10.3	5.9	5.9	22.1
Difference	−1.3	+.1	+1.1	−.1

$\chi^2 = 0.37$. $P = 0.83$

Table 45 lists the records of scutellum color in 37 F_3 progenies grown from colorless scutellum segregates of a 3:1 ratio. The two expected groups were obtained. Group A contains 2,990 individuals with no recessive types appearing. Group B contains the segregating progenies. All are reasonably close to the expected 3:1 except 673–8. For this progeny the deviation divided by probable error is 2.9. The observed segregation more nearly approximates a 15:1 ratio. The numbers in this progeny are small, however, and deviations of this magnitude are to be expected occasionally. The ratio of homozygous to heterozygous progenies is 13:24, very close to the expected 1:2.

The relation between the factors causing orange and the factors of the purple and red scutellum series has not been determined. This relation has been obscured by the linkage of one of the *So so* factor pairs with one of the aleurone factors. This linkage distorted the colorless to orange scutellum ratio in the colored aleurone class, the

only class in which segregation for the *S* factors could be detected. This difficulty can be overcome by using a homozygous colored aleurone, orange scutellum strain. Such a strain is now available, but the crosses have not been made. The data on the linkage of the aleurone factor and the So_1 so_1 factor are presented in Table 46. The percentage of crossing over was calculated by the product method to be 10.9. The aleurone factor involved is believed to be either *A* or *R*, since there is no indication of linkage between the orange scutellum factors and shrunken endosperm.

TABLE 45.—*Records of scutellum colors in 37 F_3 progenies of F_2 white segregates of a 3:1 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage orange	Dev. P. E.
	F_2	F_3	White	Orange	Total		
A (1 : 0)	P2286A-2	653-2	221	0	221	----------	--------
		653-3	207	0	207	----------	--------
		653-7	189	0	189	----------	--------
		653-9	100	0	100	----------	--------
		653-14	350	0	350	----------	--------
		653-15	325	0	325	----------	--------
	P2286B-5	653-16	206	0	206	----------	--------
		673-1	310	0	310	----------	--------
		673-6	67	0	67	----------	--------
		673-10	318	0	318	----------	--------
		673-16	119	0	119	----------	--------
		673-17	218	0	218	----------	--------
		673-20	360	0	360	----------	--------
Total	----------	----------	2,990	0	2,990	----------	--------
B (3 : 1)	P2286A-2	653-1	66	20	86	23.3	0.6
		653-4	35	11	46	23.9	.3
		653-5	57	22	79	27.8	.9
		653-6	154	55	209	26.3	.7
		653-8	31	18	49	36.7	2.8
		653-10	251	57	308	18.5	3.9
		653-11	167	51	218	23.4	.8
		653-12	104	36	140	25.7	.3
		653-13	190	56	246	22.8	1.2
		653-17	271	79	350	22.6	1.6
	P2286B-5	673-2	117	48	165	29.1	1.8
		673-3	317	102	419	24.3	.5
		673-4	214	75	289	26.0	.6
		673-5	202	69	271	25.5	.3
		673-7	199	65	264	24.6	.2
		673-8	28	3	31	9.7	2.9
		673-9	150	65	215	30.2	2.6
		673-11	183	59	242	24.4	.3
		673-12	310	123	433	28.4	2.4
		673-14	280	84	364	23.1	1.3
		673-15	48	19	67	28.4	.9
		673-18	216	56	272	20.6	2.5
		673-19	115	33	148	22.3	1.1
		673-21	298	88	386	22.8	1.5
Total	----------	----------	4,003	1,294	5,297	24.4	1.4

TABLE 46.—*Records of scutellum color in five F_3 progenies exhibiting linkage between colored aleurone and orange scutellum (So_1 so_1)*

Pedigree No.	Number of individuals				Percentage of crossing over
	Colored aleurone		Colorless aleurone		
	So_1	so_1	So_1	so_1	
843-1	214	6	49	20	10.7
843-2	135	5	34	14	13.0
843-3	256	1	72	25	2.1
843-4	289	5	70	13	13.4
843-5	384	14	83	34	12.0
Total	1,278	31	308	106	10.9

The records for scutellum color for four F_2 progenies from the cross $S_5\ S_5, So_1\ So_1, So_2\ So_2 \times s_5\ s_5, so_1\ so_1, so_2\ so_2$ are shown in Table 47. The dominant white factor S_5 has no influence on the white to orange segregations, as the deviation from a 15:1 ratio is only 1.3 times its probable error.

One F_3 progeny was segregating for the So_1 So_2 and *Sh* factor pairs. The observed ratio was 222 *So Sh*: 68 *So sh*: 16 *so Sh*: 3 *so sh*. This is a very close approximation to the 45:15:3:1 ratio expected with independent inheritance, the value for *P* being 0.75. A second progeny segregating for one of the *So* factors and *Sh* exhibited a ratio of 76 *So Sh*: 26 *So sh*: 30 *so Sh*: 8 *so sh*. This again is a close approximation to the expected 9:3:3:1 ratio, the value for χ^2 being 1.06. Thus, only 11 out of 100 repetitions would be expected to give a closer approximation to the theoretical distribution. There is, then, no evidence of linkage of the So_1 or So_2 factors with the *Sh* factor.

Certain of the progenies listed in Table 46 were segregating for brown aleurone and others for yellow endosperm. Separations for these characters were made among only the nonpurple aleurone class. Owing to the distortion of the ratios of colorless to orange scutellum, indications of linkage were sought by comparing the observed segregations of brown aleurone and yellow endosperm with the calculated 3:1 among the nonpurple aleurone class. These comparisons indicate random assortment for the So_1 So_2, *Bn*, *bn*, *and Yy* factor pairs.

TABLE 47.—*Records of scutellum color in four F_2 progenies of a cross between dominant white ($S_5\ S_5$) and orange ($so_1\ so_1\ so_2\ so_2$)*

Pedigree No.	Number of individuals			Percentage orange	Dev. / P. E.
	White	Orange	Total		
842-1	174	9	183	4.9	1.1
842-4	36	3	39	7.7	.5
842-6	396	23	419	5.5	1.0
842-10	195	12	207	5.8	.4
Total	801	47	848	5.5	1.3

YELLOW SCUTELLUMS

Yellow scutellum color is inherited as a simple recessive to the normal colorless scutellum. It has been designated by the symbol *sy*, normal white having the dominant allelomorph *Sy*.

The first yellow scutellums were observed in a selfed ear of the Blue Flour variety. Later, similar colored scutellums were observed in some of Doctor Emerson's cultures, tracing back to North American-South American maize crosses. Intercrosses between these yellows and the Blue Flour yellows indicated that all were of the same constitution.

In crosses of yellow × white scutellums the F_2 progenies show a close approximation to the expected 25 per cent of yellow scutellums. (Table 48.) The observed percentage of yellows in progenies totaling 5,014 kernels is 24.9. The range in percentages of yellow scutellums is from 21.6 to 30.9. Yellow scutellums from F_2 ears breed true for this condition, as evidenced by the data in Table 49.

The F_3 breeding behavior of F_2 whites agreed satisfactorily with the monohybrid interpretation. Of the 10 F_3 ears, 7 segregated in ratios approximating 3 whites to 1 yellow. Three ears bred true for colorless scutellums. This is a close approximation to the expected 2:1 ratio of heterozygous to homozygous forms. The detailed data are presented in Table 50.

TABLE 48.—*Records of scutellum colors in 19 F_2 progenies of a cross of white × yellow scutellums*

Pedigree No.	Number of individuals			Percentage yellow	Dev. / P. E.
	White	Yellow	Total		
740-1	181	69	250	27.6	1.4
740-2	229	63	292	21.6	2.0
740-3	270	86	356	24.2	.5
740-4	223	66	289	22.8	1.3
740-5	163	57	220	25.9	.5
740-6	103	46	149	30.9	2.5
740-7	204	70	274	25.5	.3
740-8	207	67	274	24.5	.3
740-9	254	91	345	26.4	.9
740-10	267	83	350	23.7	.8
740-11	162	53	215	24.7	.2
740-12	239	85	324	26.2	.8
740-13	202	59	261	22.6	1.3
740-14	146	59	205	28.8	1.9
740-15	219	61	280	21.8	1.8
740-16	141	42	183	23.0	.9
740-17	253	83	336	24.7	.2
740-18	142	54	196	27.6	1.2
740-19	163	52	215	24.2	.4
Total	3,768	1,246	5,014	24.9	.4

TABLE 49.—*Records of scutellum colors in eight F_3 progenies of yellow scutellum F_2 segregates*

Pedigree No.		Number of individuals		
F_2	F_3	White	Yellow	Total
176-5	356-1	0	125	125
242-9	357-9	0	30	30
	429-1	4	238	242
328-4	531-4	0	210	210
321-5	540-13	0	261	261
356-1	1021-5	0	219	219
	1021-8	0	132	132
326-1	1048-1	0	6	6
Total		4	1,221	1,225

TABLE 50.—*Records of scutellum color in 10 F_3 progenies of F_2 white segregates of a 3:1 ratio*

Group and ratio	Pedigree No.		Number of individuals			Percentage yellow	Dev. / P. E.
	F_2	F_3	White	Yellow	Total		
A (1:0)	322-8	654-3	357	0	357	----------	--------
		654-7	235	0	235	----------	--------
		654-10	234	0	234	----------	--------
Total	----------	----------	826	0	826	----------	--------
B (3:1)	322-8	654-1	214	64	278	23.0	1.1
		654-2	295	90	385	23.4	1.1
		654-4	245	70	315	22.2	1.7
		654-5	184	56	240	23.3	.9
		654-6	240	67	307	21.8	1.9
		654-8	156	52	208	25.0	0.
		654-9	178	62	240	25.8	.4
Total	----------	----------	1,512	461	1,973	23.4	2.5

A few ears showing the relation between purple and yellow scutellum color are available. The F_1 seeds from such a cross have purple scutellums. In F_2 the yellow segregation can be detected with certainty among only the nonpurple segregates. For a single *S* factor, then, the calculated ratio becomes 12 purples to 3 whites to 1 yellow. Four such progenies are listed in Table 51. The value for *P* for these progenies is 0.87. In the interaction of the *Sy* factor pair with two of the *S* factors, which would normally have a 9:7 F_2 ratio, the ratio becomes modified to 36 purples to 21 whites to 7 yellows. The value for *P* for progenies falling in this group is only 0.22. With the interaction of three *S s* factor pairs, normally exhibiting a 27:37 F_2 ratio, and the *Sy sy* factor a modified F_2 ratio of 108 purples to 111 whites to 37 yellows is expected. The value for *P* for this group of progenies is 0.56. These data indicate that there is no close linkage between the *Sy sy* factor and three of the four factors of the purple and red scutellum series.

The records for scutellum color for four F_2 progenies from the cross $S_5\ S_5$, *Sy Sy*×$s_5\ s_5$, *sy sy* are listed in Table 52. Positive and negative deviations occur with equal frequency, the cumulative deviation being negative and 1.9 times its probable error. The close approximation to the expected 3 white to 1 yellow indicates that the S_5 gene has no inhibiting influence on yellow scutellums.

TABLE 51.—*Records of scutellum color in 10 progenies segregating for purple and yellow scutellums*

Group, ratio, and pedigree No.	Number of individuals			
	Purple	White	Yellow	Total
Group 1 (12:3:1):				
324-7	224	42	13	279
325-1	160	41	18	219
325-8	179	49	16	244
327-1	171	55	16	242
Total	734	187	63	984 (P=0.87)
Group 2 (36:21:7):				
324-9	132	91	36	259
324-10	186	91	33	310
325-4	102	88	27	217
325-5	153	90	34	277
Total	573	360	130	1,063 (P=0.22)
Group 3 (108:111:37):				
325-6	67	64	21	152
328-4	86	75	30	191
Total	153	139	51	343 (P=0.56)

TABLE 52.—*Records of scutellum color in four F_2 progenies of a cross of dominant white ($S_5\ S_5$) × yellow scutellums (sy sy)*

Pedigree No.	Number of individuals			Percentage yellow	Dev./P. E.
	White	Yellow	Total		
1047-1	227	63	290	21.7	1.9
1047-2	95	34	129	26.4	.5
1047-8	134	32	166	19.3	2.5
1047-14	225	76	301	25.2	.1
Total	681	205	886	23.1	1.9

Crosses between orange and yellow scutellum strains may exhibit four kinds of ratios in F_2. In crosses heterozygous for all three factors the expected F_2 ratio is 45 white to 15 yellow to 4 orange scutellums. When the recessive gene *sy* is common to both parents, the F_1 scutellums will be yellow and the F_2 ratio will be 15 yellow to 1 orange or 3 yellow to 1 orange, depending on whether two or one of the *So* factors are segregating. When one of the recessive *so* genes is common to both parents, the other two factors being heterozygous, the expected F_2 ratio is 9 white to 3 yellow to 4 orange scutellums.

The scutellum-color segregations for F_2 progenies approximating ratios of 45:15:4 are presented in Table 53. The χ^2 value is 3.99, and *P* is only 0.14. Both the yellow and orange classes are in excess. Such a condition would be expected if there were linkage between the factor causing yellow and one of the factors causing orange scutellums. If linkage does occur, however, it must be fairly loose, as the departure from the 45:15:4 ratios is not excessive.

Data from a single cross segregating for only yellow and orange scutellums are presented in Table 54. The genotypic constitution of the orange parent was *so*$_1$ *so*$_1$ *so*$_2$ *so*$_2$ *sy sy*, so the constitution of the yellow parent must have been *So*$_1$ *so*$_1$ *So*$_2$ *So*$_2$ *sy sy* or *So*$_1$ *So*$_1$ *So*$_2$ *so*$_2$ *sy sy*, since both 15:1 and 3:1 ratios were obtained.

TABLE 54.—*Records of scutellum color in five F_2 progenies of a cross of yellow × orange scutellums*

Pedigree No.	Number of individuals			
	White	Yellow	Orange	Total
841-1	289	79	23	391
841-2	206	83	24	313
841-3	213	77	22	312
841-8	285	120	36	441
Total	993	359	105	1,457
Calculated 45:15:4	1,024.7	341.6	91.1	1,457.4

TABLE 54.—*Records of scutellum color in five F_2 progenies of a cross of yellow × orange scutellums*

Pedigree No.	Number of individuals			Percentage orange	Dev. / P. E.
	Yellow	Orange	Total		
6857-7	56	13	69	18.8	1.7
6857-15	190	63	253	24.9	.1
Total	246	76	322	23.6	.9
6857-4	234	17	251	6.8	.5
6857-8	215	9	224	4.0	2.0
6857-13	233	15	248	6.0	.2
Total	682	41	723	5.7	1.0

The fourth possible ratio, 9:3:4, has not been obtained. Such a ratio would be expected when one of the *so* factors is recessive in both parents, the remaining two factors being heterozygous.

The data for a cross involving the *Pr pr* and *Sy sy* factor pairs are presented in Table 55. The cross was made so that linkage, if present, would be in the repulsion series. There is an excess of individuals in both the double dominant and double recessive classes. The deviation is not great and may be due to chance or to crossing over in excess of 50 per cent.

Two progenies involving the *Sh* and *Sy* factors exhibited the following F_2 distributions: 225 *Sh Sy*: 77 *Sh sy* : 67 *sh Sy*: 20 *sh sy*. When allowance is made for the deficiency of shrunken seeds, the approximation to the expected 9:3:3:1 ratio is well within the limits of chance fluctuations.

A single progeny segregating for the *Su* and *Sy* factor pairs gave no indication of linkage. The F_2 distribution is as follows: 138 *Sy Su* : 37 *Sy su* : 48 *sy Su* : 20 *sy su*. The F_2 distribution for four progenies segregating for the *Y* and *Sy* factors was 545 *Y Sy* : 187 *Y sy* : 160 *y Sy* : 46 *y sy*. The fit is poor, but there is no indication of linkage. Available data, then, indicate random assortment between the *Sy sy* factor pairs and the *Pr pr*, *Sh sh*, *Su su*, and *Y y* factor pairs.

TABLE 55.—*Records of scutellum color in 11 F_2 progenies of the cross A C R Pr sy × A C R pr Sy*

Pedigree No.	Number of individuals				Pedigree No.	Number of individuals			
	Pr		*pr*			*Pr*		*pr*	
	Sy	*sy*	*Sy*	*sy*		*Sy*	*sy*	*Sy*	*sy*
742-2	259	50	61	18	742-11	144	62	42	12
742-5	144	44	64	21	742-12	90	40	43	12
742-6	165	58	65	22	742-14	183	52	46	18
742-7	154	51	36	12	742-15	167	48	55	21
742-8	134	43	52	17					
742-9	154	38	52	23	Total	1,747	525	550	191
742-10	153	39	34	15					

DISCUSSION

In the purple and red series the interaction may be such as to give rise to complementary or duplicate gene ratios. The same factor pair may show one type of behavior in one factor complex and a different behavior when operating in a different factor complex. This is of special interest in connection with certain views relative to the origin and properties of duplicate genes.

In 10 instances in maize duplicate gene ratios have been obtained. Ratios indicative of triplicate genes have been observed less frequently. The reported cases are listed in Table 56.

TABLE 56.—*Reported instances of duplicate and triplicate gene ratios in maize*

Character	Symbol	Investigator
Duplicate gene ratios:		
White seedling	w_8 w_8	Demerec (2).
Do	w_b w_c	Do.
Piebald seedling	pb_2 pb_3	Do.
Lineate leaf	li_1 li_2	Collins (1), Hutchison (5).
Premature germination	ge_6 ge_7	Mangelsdorf (9).
Do	ge_8 ge_9	Do.
Purple or red scutellum	s_2 s_3	Described here.
Do	s_2 s_4	Do.
Do	s_3 s_4	Do.
Orange scutellum	so_1 so_2	Do.
Triplicate gene ratios:		
White seedlings	$w?$ $w?$ $w?$	Demerec (2).
Germless seeds	$gm?$ $gm?$ $gm?$	Do.
Premature germination	ge_{12} ge_{13} ge_{14}	Mangelsdorf (9).

In the small grains the presence of duplicate and triplicate gene ratios has been offered as evidence in support of the hypothesis that those species with higher chromosome numbers have arisen by the duplication of chromosome sets. That the taxonomic relationships bear out this supposed origin is a general belief. Cytologists seem agreed that cytological studies of species representing the different chromosome groups and of species crosses are in support of this supposed origin.

If genetic evidence for the presence of duplicate and triplicate genes can be taken as indicative of chromosome duplication, then maize may be considered as hexaploid for a portion of its chromosome complement. Chromosome morphology in maize has not been studied sufficiently to throw much light on this problem. Chromosome doubling is, without question, a possible mode of origin of duplicate factors. However, it does not seem necessary that this must be the only method of origin. Neither does it seem necessary to believe that genes, interacting to give complementary and duplicate ratios, must have fundamentally different physical or chemical properties.

The aleurone factors *C* and *R* normally interact to produce a 9:7 ratio in F_2. Interaction between *C* and *R* results in aleurone color. The interactions between *C* and *r*, *c* and *R*, and *c* and *r*, while possibly giving a different end product in each case, are not distinguishable, and all are included in the colorless class. In a 15:1 ratio the interaction of two dominants or of one dominant and one recessive produces, visibly, the same end product. The apparent difference between the 9:7 and 15:1 ratios is merely one of dominance.

If the possible physiological processes engendered by genetic factors are considered, the fundamentality of different types of interaction largely disappears. In the 9:7 ratio for aleurone color, the *R* and *C* factors, in conjunction with other genes, initiate two chains of physiological processes. These processes are complementary in that both are necessary for the end product, aleurone color. In a 15:1 ratio the processes initiated by each dominant, in conjunction with other genes, are identical, or at least are so in terms of the end product.

Certain of the ratios in the purple and red scutellum series may be used to emphasize the importance of the residual genetic mass. A plant of the constitution S_1 S_1, S_2 S_2, S_3 s_3, S_4 s_4 will exhibit ratios

of approximately 15 colored to 1 colorless scutellum in F_2. If 15:1 ratios are caused by a duplication of chromosomes, then S_3 s_3 and S_4 s_4 must be located on the duplicate chromosomes. Now, if the S_2 S_2 pair is replaced by its recessive allelomorph s_2 s_2, the constitution will be S_1 S_1, s_2 s_2, S_3 s_3, S_4 s_4. The F_2 ratio now will be approximately 9 colored to 7 colorless scutellums. In this case S_3 s_3 and S_4 s_4 must be on nonduplicated chromosomes, since a 15:1 ratio is not obtained. Obviously these factors are on the same chromosomes in both instances. The difference between these two F_2 ratios is due entirely to the residual genetic mass and not to the factor pairs that were heterozygous.

Similar results may be obtained with other combinations of these factors, as indicated in the following comparison:

Genotypes producing ratios of—

15:1	9:7
S_1 S_1, S_2 s_2, S_3 s_3, S_4 S_4	S_1 S_1, S_2 s_2, S_3 s_3, s_4 s_4
S_1 S_1, S_2 s_2, S_3 S_3, S_4 s_4	S_1 S_1, S_2 s_2, s_3 s_3, S_4 s_4

When any two of the factor pairs S_2 s_2, S_3 s_3, and S_4 s_4 are heterozygous, the third factor being homozygous dominant, the ratio is approximately 15:1. Conversely, if any two of these same factor pairs are heterozygous, the third factor being homozygous recessive, the ratio is approximately 9:7. In either event the S_1 s_1 factor pair must be homozygous dominant.

The unusualness of this case lies, possibly, in the reactions involved in the development of scutellum color. Genetic evidence indicates that purple or red scutellum coloration is a resultant of two main reactions or series of reactions. One of these reactions is initiated by the S_1 s_1 factor pair. The second main reaction is conditioned by the other factor pairs, S_2 s_2, S_3 s_3, and S_4 s_4. Indications are that these genes produce a very similar physiological response. The combined action of the dominant allelomorphs of any two of these factor pairs, however, is required to pass a certain threshold concentration necessary for the manifestation of the end result—purple or red scutellum color.

SUMMARY

The pigments of colored scutellums are found most abundantly in the envelope of the scutellar aleurone grains.

Purple and red scutellums normally are exhibited only in the presence of purple and red aleurone. These scutellum colors are shown to be dependent upon the interaction of four factor pairs, S_1 s_1. S_2 s_2, S_3 s_3, and S_4 s_4. Of this series of factors S_1 is indispensable. The interaction is such that S_1 in combination with any two other members of the series will result in colored scutellums. Colorless scutellums must have the dominant member of the factor pairs *Ii* or S_5 s_5, or recessive s_1, or at least two of the factor pairs S_2 s_2, S_3 s_3, and S_4 s_4 in a recessive condition.

Some evidence is presented indicating that S_1 is linked with *Su*.

Dominant white scutellums are shown to be due to the action of the S_5 s_5 or *I i* factor pairs.

Orange scutellums develop in the presence of so_1 so_1, so_2 so_2. One of these factors for orange scutellums, so_1, is linked either with the *A* or *R* aleurone factor.

Yellow scutellums are inherited as a simple Mendelian recessive. The symbol *Sy sy* has been used to designate this factor pair.

The residual genetic mass was shown to be the factor determining whether 9:7 or 15:1 ratios were to result from crosses involving the same two segregating factor pairs.

LITERATURE CITED

(1) COLLINS, G. N., and KEMPTON, J. H.
1920. HERITABLE CHARACTERS OF MAIZE. I. LINEATE LEAVES. DESCRIPTION AND CLASSIFICATION OF LINEATE PLANTS—VALUE OF MAIZE AS MATERIAL FOR INVESTIGATION AND ECONOMIC IMPORTANCE OF DISCOVERING LATENT VARIATIONS. Jour. Heredity 11: 3–6, illus.

(2) DEMEREC, M.
1923. INHERITANCE OF WHITE SEEDLINGS IN MAIZE. Genetics 8: [561]–593.

(3) EYSTER, W. H.
1924. A PRIMITIVE SPOROPHYTE IN MAIZE. Amer. Jour. Bot. 11: 7–14, illus.

(4) FISHER, R. A.
1925. STATISTICAL METHODS FOR RESEARCH WORKERS. 239 p., illus. Edinburgh and London.

(5) HUTCHISON, C. B.
1922. THE LINKAGE OF CERTAIN ALEURONE AND ENDOSPERM FACTORS IN MAIZE AND THEIR RELATION TO OTHER LINKAGE GROUPS. N. Y. Cornell Agr. Expt. Sta. Mem. 60, p. 1425–1473, illus.

(6) JENKINS, M. T.
1925. HERITABLE CHARACTERS OF MAIZE. XXII—PURPLE PLUMULES. Jour. Heredity 16: 307–310, illus.

(7) LINDSTROM, E. W.
1923. HERITABLE CHARACTERS OF MAIZE. XIII—ENDOSPERM DEFECTS—SWEET DEFECTIVE AND FLINT DEFECTIVE. Jour. Heredity 14: [126]–135, illus.

(8) MANGELSDORF, P. C.
1923. THE INHERITANCE OF DEFECTIVE SEEDS IN MAIZE. Jour. Heredity 14: 119–125, illus.

(9) ———
1926. THE GENETICS AND MORPHOLOGY OF SOME ENDOSPERM CHARACTERS IN MAIZE. Conn. Agr. Expt. Sta. Bul. 279, p. [513]–614, illus.

(10) ———
1930. THE INHERITANCE OF DORMANCY AND PREMATURE GERMINATION IN MAIZE. Genetics 15: 462–494, illus.

(11) ——— and JONES, D. F.
1926. THE EXPRESSION OF MENDELIAN FACTORS IN THE GAMETOPHYTE OF MAIZE. Genetics 11: 423–455, illus.

(12) SPRAGUE, G. F.
1927. HERITABLE CHARACTERS OF MAIZE. XXVII—COLORED SCUTELLUM. Jour. Heredity 18: 41–44, illus.

(13) ———
1929. HETERO-FERTILIZATION IN MAIZE. Science (n. s.) 69: 526–527.

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THE EFFECT OF AIR DRYING ON THE HYDROGEN-ION CONCENTRATION OF THE SOILS OF THE UNITED STATES AND CANADA[1]

By ERNEST H. BAILEY, *Assistant Soil Technologist, Division of Soil Survey, Soil Investigations, Bureau of Chemistry and Soils*

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PREVIOUS WORK

In the last few years several soil investigators have reported that the reaction of soil samples changed more or less on passing from the moist field condition to the air-dry state. Some have gone so far as to declare that no hydrogen-ion determinations are reliable unless made on the fresh moist samples.

Healy and Karraker (*19*)[2] made determinations with the hydrogen electrode on six acid Kentucky soils in both the moist field condition and in the air-dry state. Five of those soils on air drying increased in acidity 0.17 to 0.55 pH unit.

Burgess, (*11*) used the hydrogen electrode on 11 acid to neutral Rhode Island soils ranging in reaction from 4.36 to 7.00 pH units and on three alkaline soils ranging from 7.40 to 7.78 pH units. Three of the 11 acid samples became 0.20 to 0.39 pH unit more acid, and the 3 alkaline samples became 0.21 to 0.23 pH unit less alkaline on drying.

Rost and Fieger (*36*) also worked with the hydrogen electrode on 36 acid soils and 4 alkaline soils from Minnesota. The acid soils in their fresh, moist condition ranged in reaction from 5.50 to 6.63 pH units and the alkaline soils from 7.34 to 7.54 pH units. The acid soils on becoming air-dry changed in reaction from 1.15 pH units more acid to 0.49 pH unit less acid, only 12 of the 36 changing less than 0.10 pH unit. The alkaline soils on drying changed in reaction from 0.38 pH unit more acid to 0.29 pH unit less acid, 2 of the 4

[1] The writer is deeply indebted to C. F. Marbut, H. G. Byers, M. S. Anderson, E. C. Shorey, Mark Baldwin, and E. F. Snyder, of the Bureau of Chemistry and Soils for their helpful suggestions; to Bessie Hooppaw, of the same bureau, for making the diagram of the electrode and electrode vessel used in the investigations, to the field men in the soil survey, and to the experiment station workers in this country and Canada who have made the work possible by collecting the moist soil samples.

[2] Italic numbers in parenthesis refer to Literature Cited, p. 41.

samples changing less than 0.10 pH unit. The general tendency was for the soils to become more acid on air drying. Remoistening the dried soils in most cases made the reaction more acid than in the air-dried samples.

Joseph and Martin (*22*) used the hydrogen electrode on arid alkaline Egyptian soils and found that drying them at 100° C. made them 0.13 to 0.75 pH unit less alkaline, but that, if the water used in the determinations stood on them for a week, the pH of the moist and of the dried samples were practically the same.

Knickmann (*26*) worked with acid German soils. He determined the "active" acidity by titrating the water extracts from the soils with sodium hydroxide, using methyl red as an indicator, instead of making hydrogen-ion determinations. He found that in some cases the acidity was twice as great after air drying for a week and four times as great after six months as that of the original moist samples. Heating the soils to above 100° C. made the acidity forty times as great. Knickmann concluded from his experiments that the increase in acidity was proportional to the humus content as it was the organic matter that caused the change in acidity on drying.

Baver (*6*) used the quinhydrone electrode in the study of cultivated Ohio soils. He found that the upper 7 inches from 12 unlimed plots, ranging in reaction from 4.41 to 5.02 pH units, changed less than 0.10 pH unit either way, on drying out. But the upper 7 inches from 12 limed plots, ranging in reaction from 7.71 to 8.14 pH units, in every case became less alkaline on air drying, ranging from 0.12 to 0.32 pH unit less alkaline. On 4 limed plots where the samples were taken at a depth ranging from 0 to 7 inches, 7 to 14 inches, 14 to 21 inches, and 21 to 28 inches, respectively, he found that on drying the acidity increased with depth in every plot. The differences in reaction between the moist and the air-dry samples varied as much as 0.63 pH unit in the deepest layer of one of the limed plots. Baver's conclusions are that fresh moist samples should be used for refined reaction studies.

Biilmann and Tovborg-Jensen (*7*) worked with the quinhydrone electrode on 19 Danish soils and found that 7 of them changed in reaction more than 0.10 pH unit on drying. These changes ranged from 0.11 to 0.20 pH unit more acid.

Achromeiko (*2*) worked with Russian podsols, podsolic soils, and chernozems, using the quinhydrone electrode. The results he obtained with the thoroughly crumbed-up and mixed soils are given in Tables 1 and 2.

TABLE 1.—*Effect on the upper 3 inches of a Russian podsolic soil of drying in the sun and at 100° C.*[1]

Treatment of soil sample	pH	Stored with capillary moisture		
		After 3 days	After 7 days	After 21 days
Crumbed soil:		*pH*	*pH*	*pH*
Fresh moist	6.20	6.22	6.26	6.23
Dried in sun	5.94	6.08	6.31	6.24
Dried in oven at 100° C. for 36 hours	4.52	5.50	6.31	6.38

[1] Data from Achromeiko (*2*) on Russian soils.

TABLE 2.—*Effect of drying soil samples at 100° C. and restorative treatment* [1]

Soil	Location	Depth	Fresh moist sample	Dried 36 hours at 100° C.	4 days after remoistening
			pH	*pH*	*pH*
Chernozem	Schatilow	Surface	5.90	4.67	6.06
Do	Anutschino	do	5.65	4.43	5.48
Do	Artscheda	do	6.24	5.35	6.34
Podsol	Agricultural Academy, Moscow	Podsol layer	6.20	6.20	6.21
Loam	do	39 inches	5.41	5.41	

[1] Data from Achromeiko (*2*) on Russian soils.

As shown in Table 1 the crumbed-up 3-inch surface layer of a podsolic soil from the experimental farm at the academy became 0.26 pH unit more acid on drying in the sun and 1.68 pH units more acid when dried in the oven at 100° C. for 36 hours. This showed that drying at high temperatures had a far more drastic effect on changing the reaction than drying the sample in the sun. Moistening the dried samples appeared to restore their pH values to approximately that of the fresh moist sample, as both the sun-dried sample and the one dried at 100° were brought back to the original pH value of the fresh moist sample by being moistened from 3 to 7 days before making the determinations.

In Table 2, the three chernozem surface soils became 0.89 to 1.23 pH units more acid after drying for 36 hours in the oven at 100° C. Unfortunately the effect of air drying on these soils was not shown. Four days after remoistening, these dried samples were restored to the approximate pH value of the fresh, moist samples, the first surface layer being 0.16 pH unit less acid, the second 0.17 pH unit more acid, and the third 0.10 pH unit less acid than the original moist sample. The podsol layer of a podsol soil and the loam subsoil, which were both very low in organic matter, did not change on being dried at 100°. From these results Achromeiko came to the same conclusion as did Knickmann (*26*)—that the increase in acidity of a soil sample on drying was dependent on the amount of organic matter present. This point will be discussed later.

But the most spectacular results have been obtained by Aarnio (*1*). He worked with the quinhydrone electrode on Finnish soils and his results are directly quoted in Tables 3 and 4.

TABLE 3.—*The influence of drying on soil reaction* [1]

Item	Days at 25° C.	Crumbly clay from south Finland (Dregsby)			Heavy clay from southwest Finland (Paattinen)			Heavy clay from southwest Finland (Paattinen)		
		Surface soil	Surface soil	Surface soil	Surface soil, 0–8 inches	Plow sole, 8–18 inches	Subsoil, 29–39 inches	Surface soil, 0–10 inches	Plow sole, 10–12 inches	Subsoil, 29–39 inches
		pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Moist sample	0	5.04	5.31	5.90	6.32	7.17	6.87	5.77	6.41	6.80
	3	4.85	5.16	5.67	6.07	7.04				
	6				5.82	6.88	6.09			
	7	4.73	5.03	5.51						
	10				5.53					
	14							5.44	5.72	
	21				4.83	6.04	5.21	5.26	5.26	5.45
	25			5.36						
	28					5.28	4.78	4.67	4.83	4.91
	32	4.25	4.50	5.14						
	35				4.44	6.77	4.33	4.33	4.37	4.07
	49				3.66	3.97	3.74	3.82	4.09	4.07
	56	3.81	3.75	4.48						
	68	3.62	3.56	4.05						
Reaction change		−1.42	−1.75	−1.85	−2.66	−3.20	−3.13	−1.95	−2.32	−2.73
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Organic matter		11.06	6.73	10.01	1.71	.54	.83	3.63	1.17	.66

[1] Data from Aarnio (*1*) on Finnish soils.

TABLE 4.—*The reaction changes of soils at 25° C.*[1]

Item	Heavy clay from southwest Finland (Pöytyä)			Heavy clay from southwest Finland		
	Days at 25° C.	Surface soil, peat covered and mixed with clay, 0–10 inches	Subsoil, 31–39 inches	Clay from Loimaa, surface humus, 0–10 inches	Clay from Loimaa, surface soil, 0–8 inches	Pöytyä, surface peat mixed with clay, 0–10 inches
		pH	*pH*	*pH*	*pH*	*pH*
Moist sample	0	4.63	5.60	5.01	4.84	4.94
	2			5.14	5.16	
	3	4.85				4.99
	4		6.12	5.23	5.21	
	5	4.90				
	6		6.24	5.23	5.34	5.02
	7	5.01				
	8		6.12	5.09	5.17	
	9	4.95				
	11	4.90	6.02	5.06	5.14	4.80
Change in reaction [2]		+.27	+.42	+.05	+.30	−.14
Dry sample	26	4.23	4.29			
	28			3.96	4.19	
	36	4.06	3.50	3.80	4.11	4.10
	42	3.79	3.48	3.79	3.79	3.97
	70	3.73				
Change in reaction		−.90	−2.12	−1.22	−1.05	−.97
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Organic matter		29.41	0.41	8.96	6.35	20.49

[1] Data from Aarnio (*1*) on Finnish soils.
[2] This change in reaction is introduced by the author of this bulletin.

The soils (Tables 3 and 4) show a great increase in acidity on drying and storing. In Table 3, the minimum change is 1.42 pH units and the maximum, 3.20 pH units more acid. Table 4 shows a minimum change in reaction at the end of 11 days, when the samples were air-dry, of only 0.05 pH unit less acid, and a maximum change of 0.42 pH unit less acid. However, at the end of a period ranging from 42 to 70 days all the samples had become very much more acid, ranging from 0.90 to 2.12 pH units more acid. These samples changed in reaction in storage far more after they were air-dry than they did while drying. Table 3 shows that the increase in acidity was, with a single exception, continuous as the days passed, whereas Table 4 shows that the soils became less acid during the first week of storage but rapidly increased in acidity after that. In general, the subsoils increased in acidity more than did the surface soils, and the surface soils high in organic matter showed less change than did those low in organic matter. From these results Aarnio naturally concluded that hydrogen-ion determinations should be made only on fresh, moist samples.

In the light of the investigations recorded in this bulletin, these results of Aarnio are inexplicable unless the samples were dried in an atmosphere containing acid fumes. Although the laboratory in which the tests discussed in this bulletin were made is comparatively free from fumes of any kind, air-dry samples of soil if allowed to remain uncovered in it become from 0.20 to 0.30 pH unit more acid in a few weeks' time.

Coles and Morison (*14*) used the quinhydrone electrode on English and Irish soils. They dried these soils from 14 to 28 days in a desiccator over sulphuric acid at room temperature and also dried them in an oven at 98° C. The results are given in Tables 5 and 6.

TABLE 5.—*Effect of drying various soils over sulphuric acid and driving all the water off in an oven at 98° C.*[1]

Soil	Description	Soil No.	Fresh, moist sample	After drying 14 days over H_2SO_4	Change [3]	After all water was driven off in oven at 98° C.	Change [3]
			pH	*pH*	*pH*	*pH*	*pH*
Calcareous grit	Sandy humus from forest	3	4.38	3.98	−0.40	3.63	−0.75
Coral rag	Arable clay soil	4	8.01	7.11	−0.90	6.25	−1.76
Kimeridge soils	Heavy silt loam pasture soil	6	5.74	5.45	−0.29	4.30	−1.44
Do	Light clay pasture soil	7	6.22	5.92	−0.30	4.97	−1.25
Do	Heavy clay pasture soil	8	7.40	6.79	−0.61	5.97	−1.43
Do	Forest subsoil of clay soil	9	4.57	4.43	−0.14	3.48	−1.09
Peat	West of Ireland	[2] 10	4.12	4.12	−0.00	3.05	−1.07
Northampton sand	Arable soil	[2] 11	7.58	6.87	−0.71	5.71	−1.87

[1] Data from Coles and Morison (*14*).
[2] Dried over H_2SO_4, 28 days.
[3] Calculated by the author.

TABLE 6.—*Recovery of soils that had been completely dehydrated in an oven at 98° C.*[1]

Soil No.	Reaction after water used in determinations had stood on samples for—										Fresh, moist sample
	0 day	1 day	3 days	6 days	10 days	15 days	21 days	28 days	42 days	56 days	
	pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
3	3.63	3.57	3.60	3.67	3.66	3.73	3.77	3.83	-------	3.90	4.38
4	6.25	6.62	7.05	7.33	7.55	7.73	7.84	7.85	-------	7.89	8.01
6	4.30	4.49	4.52	4.55	4.71	4.73	4.79	4.80	5.16	5.06	5.74
7	4.97	5.03	5.18	5.33	5.33	5.31	6.05	5.95	6.07	6.13	6.22
8	5.97	5.98	6.06	6.37	6.74	6.89	7.10	6.95	-------	7.26	7.40
9	3.48	3.67	3.77	3.78	3.80	3.92	3.98	4.00	4.09	4.35	4.57
10	3.05	3.08	3.06	3.04	3.05	3.04	3.07	3.05	-------	3.04	4.12
11	5.71	5.98	5.88	6.07	6.07	6.27	6.26	6.33	-------	6.32	7.58

[1] Data from Coles and Morison (*14*).

As is shown in Table 5, all the soils tested by Coles and Morison became considerably more acid on drying in the desiccator over sulphuric acid, with the exception of the peat which underwent no change. Complete dehydration of the samples in the oven at 98° C. made all of them still more acid (from nearly twice to nearly eight times as acid as from drying over sulphuric acid). The alkaline soils showed greater changes on drying than did the more acid soils.

In Table 6 is shown the restorative effect of allowing the water used in the determinations to stand on the soils in test tubes for varying lengths of time up to two months. Coles and Morison made only one measurement with each tube so as to avoid any effects that quinhydrone might produce by prolonged contact with the soils. In the peat soil (No. 10) there was no recovery, and in the sandy humous soil (No. 3) the recovery was very slight. In the other soils, which contained considerably more clay than Nos. 3 and 11, there was a very significant recovery, and in the four heaviest soils (Nos. 4, 7, 8, and 9) the pH after two months very nearly equaled that of the original moist soils. From these results Coles and Morison came to the conclusion that it was the mineral colloidal matter and not the organic colloidal matter which caused recovery from the heating effects. They suggested that any explanation involving the biological production of ammonia in the water-logged soils was unlikely, as in that case the organic soils should have recovered as much as, or more than the mineral soils.

By further experiments Coles and Morison found that the changes produced by heating the soils from which the exchangeable bases had all been removed by dilute hydrochloric acid were insignificant and that after treating these base-free soils with various metallic cation solutions in order to supply them with exchangeable bases, all showed a considerable decrease in pH after being dried at 98° C. They also found that after being dried the soils contained a smaller quantity of exchangeable bases than the original moist soils and that they showed increases in water-soluble calcium, potash, and phosphate. Coles and Morison therefore concluded that the exchangeable bases must in some way be responsible for the increase in acidity caused by drying.

Teräsvuori (*40*) also worked with the quinhydrone electrode on a wide variety of Finnish soils. As can be seen by comparing Tables 7 and 8 with Tables 3 and 4 he obtained very different results from those of Aarnio.

TABLE 7.—*Influence of drying the soil samples* [1] *to air dryness on the pH of the soil suspensions* [2]

Sample No.	Soil	Description of place where sample was taken	Depth in inches	Fresh, moist sample	Air-dry sample	Change
				pH	*pH*	*pH*
B238	Low-moor peat	Peat improved by mixing in of loam.	Surface soil.	5.01	5.14	+0.13
B453	Muck		0–12	5.89	6.02	+.13
B454	Heavy loam	Under B453	14–18	5.25	5.33	+.08
B455	do	Under B454	24–39	5.29	5.31	+.02
B456	Muck		0–8	6.00	5.97	−.03
B457	Sphagnum peat		28–39	4.10	4.10	.00
B458	Low-moor peat	Under B456	8–14	5.17	5.16	−.01
B459	Muck		0–9	4.69	4.85	+.16
B460	Heavy loam	Under B459	12–20	4.44	4.35	−.09
B461	Muck		0–16	4.55	4.58	+.03
B462	Heavy loam	Under B461	16–24	3.80	3.85	+.05
B463	Humous clay		0–12	4.56	4.66	+.10
B464	Heavy loam	Under B463	12–20	4.49	4.31	−.18
B465	Humous clay		0–9	5.57	5.53	−.04
B466	Heavy loam	Under B465	9–20	5.62	5.41	−.21
B467	Humous clay		0–12	6.01	5.96	−.05
B468	Heavy loam	Under B467	12–20	5.46	5.37	−.09
T1a	Humous sand	Cultivated ridge	2–4	5.51	5.87	+.36
T1b	do	do	2–4	5.70	5.59	−.11
T2a	Humous clay	Beet land	2–4	6.09	5.94	−.15
T2b	do	Beet land, freshly plowed	0–2	6.28	6.09	−.19
T3a	Fine sand	Fallow land	2–4	5.78	5.97	+.19
T3b	do	do	2–4	5.89	5.92	+.03
T4a	Low-moor peat	With growth of mixed forest	2–4	4.80	4.84	+.04
T4b	do	do	2–4	5.32	5.22	−.10
T5a	Humous clay	Alfalfa land in 1925. 2.2 tons $CaCO_3$ per acre had been received.	2–4	6.08	6.20	+.12
T5b	do	do	2–4	6.61	6.53	−.08
T6a	do	Same: In addition 15.8 tons $CaCO_3$ per acre had been received on Aug. 5, 1926.	2–4	6.49	6.38	−.11
T6b	do	do	2–4	7.18	7.20	+.02
T7a		Coniferous forest	1–2	4.12	3.98	−.14
T7b		do	1–2	4.17	4.11	−.06
T8	Clay	River bottom, about 4 inches under water.		6.02	6.00	−.02
T9	Transitional low-moor and high-moor peat.	Pea land, poor stand	1–3	5.26	5.19	−.07
T10	Humous clay	Pea land, good stand	1–3	5.30	5.02	−.28
T11	Low-moor peat	Plant improvement station	0–2	6.97	6.91	−.06

[1] Samples were collected in the fall of 1927.
[2] Data from Teräsvuori (*40*) on Finnish soils.

TABLE 8.—*Influence of the storage of soil samples*[1] *at different moisture contents on the acidity of the soil*[2]

Sample No.	Soil	Depth	Days in storage	Moisture, per cent of saturation	Moist sample	Air-dry sample	Change
					pH	*pH*	*pH*
C539	Humous loam	Surface soil	0	[3]49.0	5.60	5.27	−0.33
			33	33.3	5.61		
			33	66.7	5.48		
			33	100.0	5.65		
			68	33.3	5.49		
			68	66.7	5.46		
			68	100.0	5.62		
			124	33.3	5.36		
			124	66.7	5.21		
			124	100.0	5.55		
C540	Humous sand	Surface soil	0	[3]56.0	5.18	5.24	+.06
			33	33.3	5.17		
			33	66.7	5.07		
			33	100.0	5.44		
			68	33.3	5.15		
			68	66.7	5.07		
			68	100.0	5.31		
			124	33.3	5.05		
			124	66.7	4.93		
			124	100.0	5.45		
C541	Heavy clay	At 47 inches	0	[3]98.7	6.64	5.80	−.84
			33	66.7	5.78		
			33	100.0	6.56		
			68	33.3	5.32		
			68	66.7	5.80		
			68	100.0	7.23		
			124	33.3	5.00		
			124	66.7	5.35		
			124	100.0	5.95		
C542	Low-moor peat	Surface soil	0	[3]78.2	4.52	4.63	+.11
			30	33.3	4.54		
			30	66.7	4.51		
			30	100.0	4.65		
			65	33.3	4.52		
			65	66.7	4.37		
			65	100.0	4.49		
			121	33.3	4.46		
			121	66.7	4.29		
			121	100.0	4.81		
C543	Muck	Surface soil	0	[3]64.1	4.93	4.97	+.04
			30	33.3	4.75		
			30	66.7	4.64		
			30	100.0	5.08		
			65	33.3	4.66		
			65	66.7	4.61		
			65	100.0	5.20		
			121	33.3	4.56		
			121	66.7	4.50		
			121	100.0	5.33		

[1] Samples were collected in the summer of 1929.
[2] Data from Teräsvuori (*40*) on Finnish soils.
[3] Initial moisture content in terms of per cent saturation.

As can be seen in Tables 7 and 8, 17 of the 40 soil samples, on which Teräsvuori made determinations in both the moist and in the air-dry condition, changed more than 0.10 pH unit on air drying. Seven of these samples became less acid and 10 became more acid. Five samples changed more than 0.20 pH unit, and a heavy clay subsoil at a depth of 47 inches changed 0.84 pH unit—the greatest change of any sample on drying out. The subsoils low in organic matter changed as much as did any of the surface soils high in organic matter.

Table 8 shows the effect Teräsvuori obtained on the soil samples by storing them at different moisture contents for several months, as well as the effect of air drying. The samples which were one-third and two-thirds saturated with water became increasingly more

acid with storage. The samples that were two-thirds saturated did not increase in acidity as much as did the corresponding ones that were one-third saturated. In general, there was a tendency for the water-saturated samples to become less acid as time passed. One soil, C539, became very slightly more acid when stored in a water-saturated condition, the change being less than 0.10 pH unit. Sample C541, a heavy clay subsoil, was most erratic in its behavior. It changed more than any other of Teräsvuori's soils on passing from the moist to the air-dry condition, somewhat resembling Aarnio's (*1*) clays in its behavior, as shown in Tables 3 and 4.

In view of the wide variance of the recorded data and the fact that the air-dried condition is the usual form in which the soil samples are most readily brought to the laboratory and kept for examination, it seemed very important to determine definitely to what extent alterations of pH by air drying actually occur and, if such changes occur, to ascertain what restorative measures may be used to obviate the inconvenience of collecting fresh moist samples and to avoid any uncertainties arising from seasonal variations in field moisture conditions (*10, 12, 15, 16, 24, 27, 29, 31*).

COLLECTION AND PREPARATION OF SAMPLES

It seemed desirable that the investigations should cover a wide range of soil types developed and existing under varying climatic conditions and that the samples should receive uniform treatment throughout. Therefore about three years ago the cooperation of the field men in the soil survey and of some of the experiment station workers of this country and of Canada was asked in collecting moist horizon samples from representative profiles in their localities. Tin cans holding about a pint of soil, with covers which fitted tightly enough to prevent rapid air drying of the sample but were not sufficiently air-tight to induce anaerobic conditions, were furnished for collecting the samples. In each case moist samples were collected from representative portions of each horizon of the virgin profile, including the humous or the leaf-mold layer. Each can was labeled as to location, soil type, and depth at which the sample was taken, and it was sent to the laboratory. On reaching the laboratory each sample was immediately carefully mixed so as to have it as homogeneous as possible, and from 4 to 18 determinations were made while it was still moist. Then each sample was air-dried in a room separated from the laboratory so as to be free from fumes of any kind, again thoroughly mixed and run through a 2-mm. mesh sieve, and from 4 to 18 determinations were made in the air-dry state.

The virgin profiles, from which the horizon samples were collected, were selected with a view of covering a wide range of geographical and climatic regions within the United States, Porto Rico, and Canada. They also covered a wide range of soil groups. They included 6 representatives from the humid prairies, 3 from the brownish-red profiles bordering on pedocals, 6 from the chernozem group, 1 from the reddish-brown pedocals, 3 from the desert soils, 10 from the lateritic group, 3 from the imperfectly drained profiles of lateritic regions, 4 from the immature soils, 12 from the podsols, 2 from the degraded chernozems, and 15 from the podsolic profiles. All the soils from this

country and Porto Rico are identified as soil types in terms of the soil survey classification. The groups are in accordance with Marbut's (*30*) and Glinka's (*18*) classifications.

DESCRIPTION OF APPARATUS AND METHOD USED

In the investigations the hydrogen-ion concentration was measured by means of a method developed by the author for routine examination of soil samples for the soil survey as a result of his study of other published methods (*4, 7, 8, 13, 17, 21, 33, 38*). The apparatus is of the bubbling hydrogen type and is similar to that of Bray (*9*) although developed independently before the publication of the Bray method. In both methods the hydrogen enters at the bottom of a thick-walled pyrex vessel, the lower part of which is funnel shaped, and the soil is kept in suspension by the stream of hydrogen bubbles. The apparatus differs from that of Bray in that it has no Gooch crucible inserted in the lower part of the electrode vessel to break the stream of hydrogen into a fine spray. Experience has shown that purification of the tank hydrogen is not necessary. The details of the apparatus are shown in Figures 1 and 2.

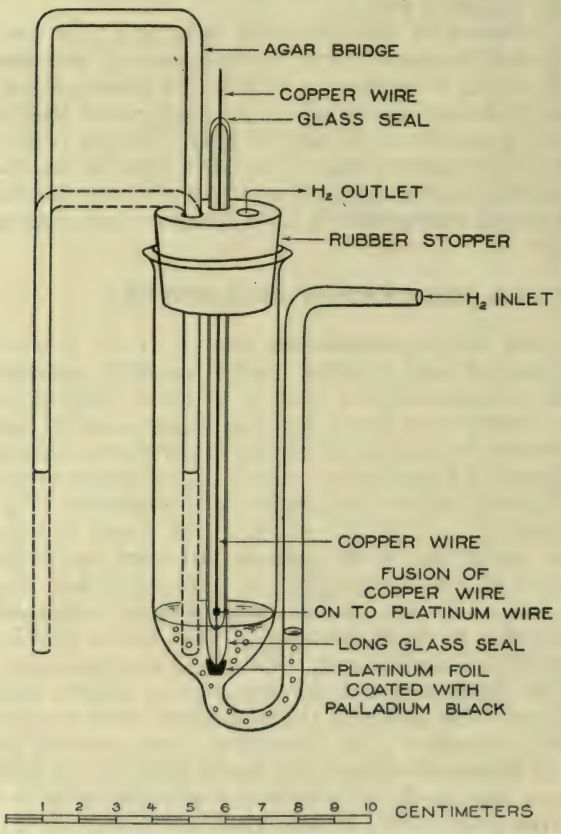

FIGURE 1.—Hydrogen electrode and electrode vessel for soil suspensions

The agar bridge employed in this method consists of a U-shaped glass tube filled with 5 per cent agar made up with a 3.5 molar potassium chloride solution (*7*). Any strength potassium chloride from N/10 to a saturated solution gives equally good results. The end of the U tube which is to be dipped into the soil suspension must be kept immersed in distilled water while the apparatus is in use and not actually employed in taking readings. Otherwise potassium chloride is dissolved by the soil suspension, and the acidity may be increased through base exchange. The bridge is made (*7*) by sucking the melted agar solution into the dry tube, care being taken to have it completely filled. Several agar bridges are made up at a time. When not in

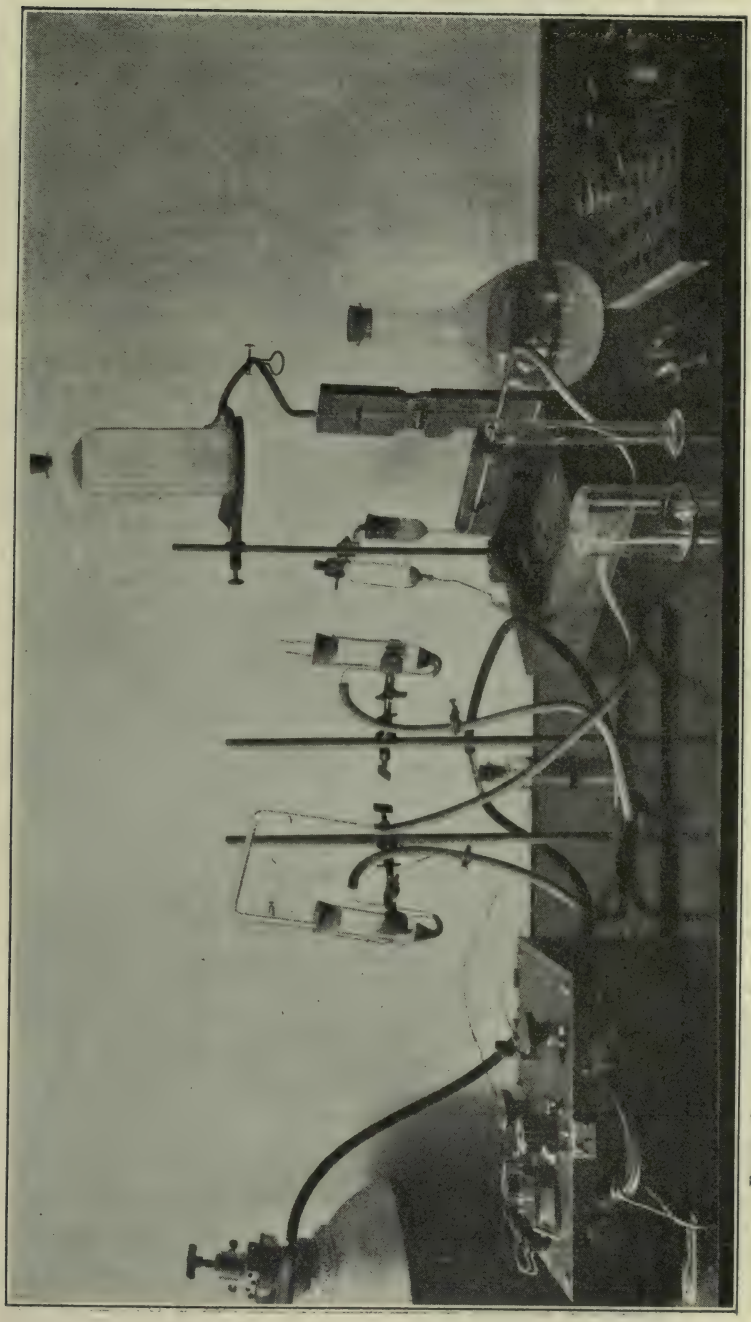

FIGURE 2.—Apparatus for the electrometric measurement of the hydrogen-ion concentration of soils with the hydrogen electrode

use, they are kept from drying out by being placed in a damp chamber. In this way one bridge may last for several months.

The other end of the agar bridge is pushed into a rubber tube filled with a saturated solution of potassium chloride. The rubber tube is joined to a glass tube provided with a glass stopcock. The glass tube widens into a small cylindrical vessel. Both the glass tube and the vessel are filled with a saturated solution of potassium chloride. Between the glass stopcock and the rubber tube, another glass tube, also provided with a glass stopcock, joins the first glass tube at right angles. This tube leads to an elevated reservoir likewise containing a saturated potassium chloride solution. (Fig. 2.) By carefully operating the two stopcocks, air bubbles can be eliminated when the agar bridge is connected with the rubber tube. The cylindrical potassium chloride vessel connects with a saturated potassium chloride calomel electrode (*17*, *38*).

The electrodes are made by welding a small piece of platinum foil one-fourth inch square (*13*) or smaller (a point of platinum wire gives as good results) to a piece of platinum wire one-half millimeter in diameter and about three-fourths inch long. The other end of the platinum wire is welded to a piece of copper wire (*21*) of the same diameter and about 7 inches long. With the exception of about an inch and a half of the free end of the copper wire, the rest of it and the platinum wire are encased in a thick-walled glass tube of which the outside diameter is one-fourth inch. The long glass seal on the platinum wire (from one-fourth to three-fourths inch in length) extends a little way onto the foil in order to give strength. A short glass seal is fastened to the copper wire at the other, or upper, end to hold it firmly. (Fig. 1.)

The electrodes are thoroughly cleaned in chromic sulphuric acid cleaning solution, carefully rinsed in distilled water, and are given a medium-gray coat of palladium black from a 3 per cent palladium chloride solution containing 1½ per cent hydrochloric acid (*4*, *38*). Direct current of 115 volts is used in series with a 15-watt lamp. To coat an electrode, the copper wire at its upper end is connected by means of a screw clamp soldered to an insulated copper wire leading from the negative pole of the lighting system and another electrode is connected in like manner with the positive pole. Both are then dipped into the palladium chloride solution. In a few seconds the negative electrode has attained a medium-gray coat. After coating, the electrodes are carefully washed in tap water and then rinsed with distilled water. They must then be allowed to stand in distilled water for about 12 hours before being used if certainty of constant readings is to be assured (*8*). In the opinion of the writer this is necessary in order to remove all the acid palladium chloride solution held by occlusion in the palladium coat. Electrodes will stand from six weeks to two months constant use before they must be recoated and will last almost indefinitely if not used after being coated, provided they are kept covered with distilled water.

For renewal of the electrode, the old coat is first removed by connecting the electrode with the positive pole of the coating apparatus described and the uncoated electrode with the negative pole, then both electrodes are dipped into a 1:1 aqueous hydrochloric acid solution (*38*). This dissolves the coat in a few seconds. The electrode is then cleaned and recoated as already described.

A high-grade portable potentiometer is used, which gives accurate enough readings for soil work. It is shown on the left in Figure 2. Its positive pole is connected by means of an insulated copper wire to the calomel electrode.

When possible, 1 part of soil by volume to 2 parts of distilled water are used. (This volume relation approximates a weight relation of 1:3 for the humus layers and 1:1½ for the mineral soil horizons.) In the case of clays twice that amount of water is necessary, otherwise the soil suspension would be a thick paste. It has been found most convenient to use a small spoon holding 1½ cubic centimeters of soil, when level full, as a measure and to add to this quantity of soil 3 cubic centimeters of boiled distilled water. The mixture is shaken up in duplicate in short thick-walled pyrex tubes, about 2 inches in length, with No. 4 rubber stoppers tightly pushed into their mouths. (Fig. 2.) Usually enough samples of soil are measured and mixed with water at a time for half a day's work. It appears to make no difference whether the water stands on the soil for 5 minutes or for 6 or 7 hours.

The stream of hydrogen is divided by means of a Y tube into two streams. Each stream is conducted by a rubber hose to an electrode vessel held in an upright position by a clamp attached to the electrode stand. (Fig. 2.) On each inlet hose is a screw clamp to regulate the flow of hydrogen so that there will be an equal flow into each vessel at the same time. While the hydrogen is running into the duplicate electrode vessels the contents of each of the two duplicate tubes of soil suspension are poured simultaneously into each, care being taken that all the soil from each tube is shaken into each vessel. On transferring the soil suspensions from the shaking tubes to the electrode vessels, a 3-hole stopper with a coated electrode inserted through one of its holes is thrust into each so that the blackened portion of the platinum is completely submerged in the suspension. The hydrogen is run in fast enough to keep the soil in each vessel in complete suspension. It appears to make no difference how fast the hydrogen bubbles pass through, so long as the soil particles are equally distributed throughout the suspension. With acid soils equilibrium is attained in from one-half minute to 5 minutes, whereas alkaline soils require from 5 to 10 minutes. When a reading of one of the duplicates is taken, the potentiometer is first balanced with the standard cell, then the copper wire from its negative pole is connected, by means of a screw clamp soldered to its other end, with the corresponding hydrogen electrode, and the free end of the agar bridge is removed from the glass of distilled water and pushed through one of the two remaining holes in the stopper until it comes in contact with the suspension. The hydrogen escapes through the third hole. The reading is then taken, together with the temperature from a thermometer immersed in water. At the same time that the agar bridge is shoved through one of the holes of the stopper into the suspension of one of the duplicates, a solid glass rod of the same diameter is stuck into one of the stopper holes of the other so as to give equality of pressure. The other duplicate is then similarly treated. The stream of hydrogen is provided with a mercury trap which serves as a safety valve in case the duplicates become clogged. The hydrogen then escapes through the mercury. The readings are always taken while the hydrogen is being bubbled through the suspension. While one pair of duplicates is coming to equilibrium, another pair of dirty electrodes with the

dirty stoppers, electrode vessels, and shaking tubes are being washed with tap water and rinsed with distilled water, the readings in millivolts are being converted by means of conversion tables into pH values, and the results tabulated. At the beginning of each day the apparatus and the hydrogen electrodes are checked by making determinations of samples of soil, the pH value of which is known and its constancy well established. By following the procedure outlined above, one person without assistance is able to do from 60 to 70 single determinations or from 30 to 35 duplicate determinations in a 7½-hour day.

The results of this method on a number of soil samples were compared with the unpublished results obtained on them by five other investigators of wide experience in making hydrogen-ion determinations. These investigators used different electrometric methods. Table 9 shows the comparison of the results obtained.

TABLE 9.—*Comparison of method with data obtained by five other investigators with the hydrogen electrode and the quinhydrone electrode*

Sample No.	A		B	C		D	E	Bailey	
	H. E.[1]	Q. E.[1]	Q. E.	H. E.	Q. E.	Q. E.	Q. E.	H. E.	Q. E.
	pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
2507	4. 59	4. 44	4. 70					4. 62	4. 56
2508	4. 79	4. 62	4. 70					4. 84	4. 78
2509	4. 68		4. 69					4. 60	4. 51
2601	4. 53	4. 48						4. 47	
2602	5. 04	5. 00						5. 05	
2603			5. 41					5. 49	5. 43
2604			4. 79					4. 85	4. 90
I	7. 38							7. 38	
II	9. 16							9. 11	9. 13
III	7. 94							8. 02	
A				6. 50	6. 65			6. 46	6. 44
B				5. 08	5. 14			4. 97	5. 03
C				5. 60	5. 56			5. 50	5. 45
34177						4. 55		4. 61	4. 43
34178						4. 65		4. 64	4. 47
34191						6. 41		5. 96	5. 92
34194						4. 90		4. 90	4. 87
34196						5. 46		5. 40	5. 28
C_1						4. 70		4. 30	4. 36
C_6						6. 25		4. 75	5. 91
34138						4. 28		4. 25	4. 29
34139						4. 33		4. 30	4. 29
34141						4. 25		4. 59	4. 54
34161						4. 72		4. 74	4. 63
34165						4. 51		4. 55	4. 49
52c							7. 35	6. 33	
58b							5. 30	5. 17	
62a							6. 95	5. 95	
62b							7. 18	5. 94	
65b							5. 08	5. 00	
65c							6. 16	5. 29	
87c							4. 58	4. 40	

[1] H. E.=hydrogen electrode; Q. E.=quinhydrone electrode.

Table 9 shows excellent agreement between the writer's results and those of A, and good agreement with those of C, with the hydrogen electrode, good agreement with those obtained by A, B, and C with the quinhydrone electrode on Maryland soils, fair agreement with those of D with the quinhydrone electrode on Ohio soils, and very poor agreement with those of E with the quinhydrone electrode on Mississippi River bottom soils from Mississippi. The splendid agreement between the author's hydrogen electrode results and those

of A, even with the three alkaline soils, are especially interesting. The committee on soil reaction measurements of the International Society of Soil Science (*37*) recommends a hydrogen electrode vessel of the Clark type for alkaline soils in preference to one of the bubbling type, as the removal of carbon dioxide by the current of hydrogen introduces an error. Investigator A used a Clark type of electrode vessel. The close agreement between his hydrogen electrode results and those of the author on the alkaline soils strongly indicates that the author's bubbling type of electrode vessel did not introduce any serious error.

One of D's quinhydrone results (sample No. C_6) was 1.5 pH units less acid than the corresponding hydrogen electrode value obtained by the writer and 0.34 pH unit less acid than the writer's quinhydrone electrode value. Only three of E's seven quinhydrone results came within 0.20 pH unit of those obtained by this hydrogen electrode method. The other four samples showed E's quinhydrone results to be 0.87 to 1.24 pH units less acid than those obtained by the writer with the hydrogen electrode method. These seven samples were tested for their manganese dioxide content by W. O. Robinson of the division of soil chemistry and physics, Bureau of Chemistry and Soils, as soils from lateritic regions are likely to be high in that substance. The three samples, which showed differences of less than 0.20 pH unit between the two methods, all had a very low manganese dioxide content. Two samples (62b and 65c), showing differences between the two methods of 1.24 and 0.87 pH units, respectively, both contained small quantities of manganese dioxide. One sample (52c), which showed a difference of 1.02 pH units between the two methods, contained considerable manganese dioxide, and one sample (62a), showing a difference between the two methods of 1.0 pH unit, contained no manganese dioxide. This last case indicates that there are other substances besides manganese (*20*, *23*, *32*) and factors other than alkalinity (*5*, *7*, *28*) that disturb the quinhydrone electrode. Because of these results, showing the quinhydrone electrode to be less reliable than the hydrogen electrode, and because of the wide variety of soils used in these investigations, including soils high in manganese as well as alkaline soils, only the hydrogen electrode was used in this work.

EXPERIMENTAL DATA

The data obtained on the hydrogen-ion concentration of fresh, moist profiles, together with that obtained on the same profiles after being air-dried, and the results of restorative treatments are given in Tables 10 to 19. It will be noted in these tables that in each case the mean pH values are given, together with the range of individual values. The mean values are not a true mean of the hydrogen-ion concentrations, since the pH value is a logarithmic function. They do, however, represent the mean range of variation of the 4 to 18 determinations made for each condition of each sample.

Twenty profiles, or 31 per cent of the 64 profiles studied, showed a change of more than 0.10 pH unit in some of their horizons on air drying; 42 horizon samples, or 13 per cent of the 327 horizon samples examined, changed more than 0.10 pH unit on passing from the moist to the air-dry condition; and 26 horizon samples, or 8 per cent of the total number examined, changed more than 0.20 pH unit on drying.

Only 2 of the 64 profiles studied contained horizons that changed 0.50 pH unit or more on becoming air-dry. The samples showing the greatest change were the A horizon (1½ to 6 inches) of a degraded chernozem from Alberta, Canada (Table 17), which changed 0.51 pH unit, and one from a podsolic profile (8 to 12 inches), from western Oregon, which changed 0.68 pH unit. (Table 18.) In both samples the change was toward greater acidity. These results differ considerably from those of Aarnio (*1*), as shown in Tables 3 and 4, who had a minimum increase in acidity of 0.90 pH unit and a maximum of 3.20 pH units with his 14 samples on air drying and storing. They agree fairly well with those obtained by the other investigators (*2*, *6*, *7*, *11*, *14*, *19*, *26*, *36*, *40*).

Where the change on drying and storing exceeded 0.10 pH unit, with only two exceptions, namely, in the two deepest layers of a podsolic profile from Wisconsin (Table 19), it was toward greater acidity. These results in this regard agree in general with those of Aarnio and the other investigators (*1*, *2*, *6*, *7*, *11*, *14*, *19*, *26*, *36*, *40*).

With few exceptions the greatest change on air drying took place in the upper layers which were high in organic matter. In this respect these results differ sharply from those of Aarnio (*1*) and from those of Baver (*6*) both of whom found the reverse to be true, but they agree with results obtained by Knickmann (*26*) and Achromeiko (*2*).

With only one exception (the humus layer of a reddish-brown pedocal, Table 12) no horizon sample which was neutral or alkaline in the fresh, moist condition changed more than 0.10 pH unit on air drying. This disagrees with the findings of some of the other investigators (*1*, *6*, *11*, *36*) who found that alkaline and neutral soils as well as acid soils change more than 0.10 pH unit on becoming air-dry.

As has been noted, the greater part of the profiles examined did not change in pH value more than 0.10 pH unit in any of their horizons on air drying. Of the samples that changed more than this amount, some from several groups of profiles were more easily restored to their original pH values by submergence in the water used in the determinations from 18 to 24 hours. (Tables 12–15.) Horizon samples from other groups of profiles responded better to the restorative treatment of being moistened but not saturated with distilled water (to simulate field conditions), and allowed to stand in that condition with the covers on the cans to prevent rapid evaporation from 4 to 7 days (Tables 16–18). One group of profiles contained some horizons which were restored more closely by one treatment and others which responded better to the other treatment. These are shown in Table 19.

None of the humid prairie profiles, the brownish-red soils bordering on the pedocals, and, with the exception of one surface layer, none of the pedocals, consisting of the chernozems, the reddish-brown, and the desert soils, changed more than 0.10 pH unit in any horizons on drying. (Tables 10–12.) This statement also applies to four-fifths of the lateritic soils (Table 13), to three-fourths of the immature profiles (Table 15), to two-thirds of the imperfectly drained soils of lateritic regions (Table 14), to more than one-half of the podsolic soils of the Eastern and Midwestern States (Table 19), and to approximately one-half of the podsols and the degraded chernozems (Tables 16 and 17).

TABLE 10.—*Hydrogen-ion determinations of humid prairie soils taken in the moist field condition and in the air-dry state*

Soil type	Location	Depth	Moist, field sample	Air-dry sample	Change from moist field condition
		Inches	*pH*	*pH*	*pH*
Carrington silt loam [1]	Guthrie County, Iowa	0–2	6.13±.10	6.08±.05	−0.05
		8–12	5.58±.05	5.56±.03	−.02
		20–24	5.94±.06	5.91±.02	−.03
		46–50	6.16±.13	6.09±.02	−.07
		68–72	6.02±.08	6.03±.04	+.01
Do.[2]	Butler County, Iowa	0–1	5.16±.01	5.18±.01	+.02
		1–5	5.26±.01	5.22±.03	−.04
		11–15	5.63±.02	5.60±.00	−.03
		18–22	5.63±.02	5.61±.01	−.02
		27–31	5.62±.00	5.65±.02	+.03
		40–44	6.00±.05	6.00±.00	.00
Tama silt loam [2]	Vernon County, Wis.	0–6	5.02±.01	5.03±.01	+.01
		6–15	5.44±.03	5.48±.01	+.04
		15–21	5.16±.04	5.24±.01	+.08
		21–32	5.46±.03	5.53±.04	+.07
		32–44	5.35±.03	5.34±.04	−.01
		44–60	5.90±.02	5.95±.03	+.05
Do.[1]	Guthrie County, Iowa	0–2	6.38±.07	6.38±.05	.00
		4–8	6.53±.04	6.45+.02	−.08
		11–15	5.28±.02	5.30±.01	+.02
		17–21	5.17±.04	5.17±.04	.00
		25–29	5.25±.03	5.26±.04	+.01
		40–44	5.57±.05	5.57±.04	.00
		48–52	5.81±.06	5.78±.01	−.03
		74–78	6.16±.09	6.19±.06	+.03
Do.[2]	Butler County, Iowa	0–1	4.98±.02	4.98±.01	.00
		4–8	6.22±.03	6.19±.01	−.03
		14–18	5.65±.02	5.67±.00	+.02
		27–31	5.64±.01	5.63±.02	−.01
		40–44	5.97±.02	5.99±.00	+.02
		54–58	6.21±.01	6.21±.01	.00
Dickinson fine sandy loam [2]	Butler County, Iowa	0–4	5.63±.02	5.59±.00	−.04
		14–18	5.43±.00	5.42±.01	−.01
		29–33	5.13±.00	5.13±.00	.00
		44–48	5.30±.01	5.28±.01	−.02

[1] 8 determinations were made of each sample in each condition.
[2] 4 determinations were made of each sample in each condition.

TABLE 11.—*Hydrogen-ion determinations of brownish-red soils, bordering on pedocals, taken in the moist, field condition and in the air-dry state and the effects of restorative treatments on the pH of some of the air-dried samples* [1]

Soil type	Location	Depth	Moist field sample	Air-dry sample	Change from moist field condition	Air-dry soil in contact with water 18–24 hours	Change from moist field condition	Air-dry soil moistened 4–7 days before	Change from moist field condition	Air-dry soil moistened 30 days before	Change from moist field condition
		Inches	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Las Posas stony fine sandy loam	Oceanside area, Calif.	0–½	6.39±0.01	6.32±0.00	−0.07	6.41±0.02	+0.02	6.01±0.01	−0.38	5.54±0.03	−0.85
		½–4	6.57± .03	6.49± .04	−.08	6.56± .04	−.01	6.54± .03	−.03	6.23± .00	−.34
		8–12	7.00± .07	6.97± .05	−.03						
		22–26	7.07± .05	7.08± .03	+.01						
Fallbrook sandy loam	do	0–¼	6.97± .06	6.95± .05	−.02	6.97± .03	0				
		1–5	6.66± .01	6.66± .01	.00						
		12–16	7.13± .06	7.17± .02	+.04						

[1] 8 determinations were made of each sample in each condition.

The horizons appreciably altered by air drying, which responded best to the treatment of submergence from 18 to 24 hours in the distilled water used in the determinations, were from the reddish-brown pedocal profile (Table 12), from the lateritic group (Table 13), from the imperfectly drained soils of lateritic regions (Table 14), and from the immature profiles (Table 15).

TABLE 12.—*Hydrogen-ion determinations of pedocal soils taken in the moist field condition and in the air-dry state*

CHERNOZEMS

Soil type	Location	Depth	Moist field sample	Air-dry sample	Change from moist field condition
		Inches	*pH*	*pH*	*pH*
Weyburn clay loam [1]	Saskatchewan, Canada	0–2	7.88±0.03	7.91±0.08	+0.03
		2–6	7.08± .08	6.99± .09	−.09
		10–14	8.06± .07	7.97± .05	−.09
Do [2]	do	22–26	8.49± .04	8.47± .05	−.02
		46–50	8.18± .09	8.22± .05	+.04
		58–62	8.48± .05	8.48± .04	.00
Melfort silt loam [1]	do	0– 1½	7.99± .06	7.98± .09	−.01
		3–7	7.67± .08	7.75± .08	+.08
		10–14	6.93± .08	6.89± .06	−.04
		16–20	7.19± .06	7.15± .02	−.04
Do.[2]	do	33–37	8.63± .08	8.54± .05	−.09
		74–78	8.60± .13	8.52± .05	−.08
Moody silt loam [3]	Moody County, S. Dak	0–4	7.36± .03	7.36± .03	.00
		4–11	7.06± .03	7.03± .03	−.03
		11–20	6.82± .00	6.82± .02	.00
		20–34	7.31± .01	7.33± .02	+.02
Do.[2]	do	34–44	8.70± .01	8.70± .05	.00
		44–56	8.69± .03	8.66± .03	−.03
		56–78	8.67± .02	8.68± .02	+.01
Barnes loam [3]	Kingsbury County, S. Dak	0–2	8.05± .03	8.05± .02	.00
		2–11	7.83± .00	7.82± .01	−.01
		11–23	7.40± .02	7.41± .04	+.01
Do.[2]	do	23–44	8.41± .09	8.43± .07	+.02
		44–53	8.61± .08	8.57± .08	−.04
		53–64	8.63± .06	8.65± .04	+.02
		64–73	8.48± .04	8.51± .04	+.03
Summit silt loam [1]	Ellis County, Kans	0–6	8.43± .03	8.46± .03	+.03
		26–30	8.35± .05	8.36± .04	+.01
Do [4]	do	50–54	8.36± .09	8.35± .08	−.01
Do.[5]	do	88–92	8.03± .07	8.03± .05	.00
		118–122	7.85± .05	7.84± .04	−.01
		142–146	8.88± .02	8.88± .02	.00
Pullman silty clay loam [1 6]	Potter County, Tex	0–6	6.68± .13	6.72± .05	+.04
		10–20	7.78± .11	7.72± .05	−.06
Do.[4]	do	30–40	8.17± .10	8.21± .04	+.04
Do.[5]	do	54–64	7.96± .13	7.98± .11	+.02
		70–75	8.02± .15	8.04± .05	+.02
		90–95	8.31± .11	8.30± .05	−.01

REDDISH-BROWN SOILS

Merriam sandy loam [1 7]	Oceanside area, California	0– ½	7.23±0.06	6.94±0.04	−0.29
		10–14	6.20± .03	6.18± .02	−.02
Do.[4]	do	21–25	7.71± .08	7.72± .02	+.01
Do.[5]	do	36–40	8.57± .06	8.64± .03	+.07
		60–64	8.53± .06	8.51± .04	−.02

[1] 8 determinations were made of each sample in each condition.
[2] Lime zone.
[3] 4 determinations were made of each sample in each condition.
[4] Lime concretions.
[5] Full of lime concretions.
[6] Southern chernozem; first 2 horizons, dark chocolate brown; third horizon, medium chocolate brown.
[7] The air-dry sample, after being in contact with water from 18 to 24 hours, showed a pH of 7.21±0.02, the change from the moist field condition being −0.02 pH. On moistening the air-dry sample from 4 to 7 days before, the pH became 6.56±0.04, showing a change from the moist field condition of −0.67 pH. The air-dry sample, after being stored for 30 days in a moistened condition, had a pH of 5.92±0.04, which gave a change of −1.31 pH from the moist field condition.

TABLE 12.—*Hydrogen-ion determinations of pedocal soils taken in the moist field condition and in the air-dry state*—Continued

DESERT SOILS

Soil type	Location	Depth	Moist field sample	Air-dry sample	Change from moist field condition
		Inches	*pH*	*pH*	*pH*
Ralston loam [1]	Basin area, Wyoming	0- ½	8.60±0.03	8.62±0.02	+0.02
Do.[4]	do	2-6	8.51± .04	8.61± .08	+.10
Do.[5]	do	18-22	9.14± .09	9.12± .02	−.02
Do.[5]	do	33-37	8.21± .09	9.24± .02	+.03
Ralston sandy loam [1]	do	0-2	8.25± .00	8.20± .07	−.05
Do.[4]	do	3-7	8.48± .08	8.48± .04	.00
Do.[5]	do	9-14	8.74± .11	8.72± .05	−.02
Do.[5]	do	16-20	9.04± .11	9.07± .04	+.03
Do.[5]	do	30-34	9.16± .13	9.16± .04	.00
Chipeta fine sandy loam [1]	do	0-1	8.51± .04	8.60± .08	+.09
Do.[4]	do	6-10	8.63± .10	8.73± .04	+.10
Do.[5]	do	16-20	8.70± .07	8.77± .07	+.07
Do.[5]	do	23-26	8.89± .07	8.79± .06	−.10

[1] 8 determinations were made of each sample in each condition.
[4] Lime concretions.
[5] Full of lime concretions.

One profile (five horizon samples) belonging to the reddish-brown pedocal group was examined (Table 12). Its humus layer became 0.29 pH unit more acid on drying. This was the only alkaline sample (pH 7.23) in the fresh, moist condition which showed a change of more than 0.10 pH unit on becoming air-dry.

Ten profiles (49 horizon samples) of the lateritic group were studied (Table 13). Three of the upper layers of two of the profiles became more than 0.10 pH unit more acid on air drying.

TABLE 13.—*Hydrogen-ion determinations of lateritic soils taken in the moist field condition and in the air-dry state and the effects of restorative treatments on the pH of some of the air-dried samples*

Soil type	Location	Depth	Moist field sample	Air-dry sample	Change from moist field condition	Air-dry soil in contact with water 18–24 hours	Change from moist field condition	Air-dry soil moistened 4–7 days before	Change from moist field condition	Air-dry soil moistened 30 days before	Change from moist field condition
		Inches	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Rio Piedras clay [1]	San Juan area, Porto Rico	0–2	6.03±0.04	6.03±0.05	0	6.03±.04	0				
		2–12	5.18±.04	5.17±.04	−.01						
		12–30	5.20±.03	5.18±.01	−.02						
		30–48	4.99±.03	5.02±.03	+.03						
		48–60	4.41±.03	4.42±.02	+.01						
Bayamon clay loam [1]	do	0–2	4.81±.02	4.65±.05	−.16	4.80±.02	−.01	5.14±0.01	+0.33	4.82±0.03	+0.01
		2–12	4.81±.02	4.81±.06	.00						
		12–30	4.81±.02	4.85±.02	+.04						
		30–48	4.81±.02	4.83±.04	+.02						
		120–144	4.79±.04	4.76±.03	−.03						
Red Bay fine sandy loam [2]	Mobile County, Ala	0–2	5.66±.04	5.62±.00	−.04	5.63±.02	−.03				
		5–9	5.76±.06	5.80±.00	+.04						
		24–28	5.29±.00	5.26±.03	−.03						
		44–48	4.95±.05	4.97±.01	+.02						
Ruston loamy fine sand [2]	do	0–1½	5.65±.04	5.63±.00	−.02	5.59±.01	−.03				
		5–9	5.84±.01	5.85±.04	+.01						
		15–19	5.18±.05	5.21±.08	+.03						
		42–46	5.26±.03	5.29±.03	+.03						
Blakely loam [1]	Dougherty County, Ga	0–½	5.74±.02	5.71±.01	−.03	5.75±.05	+.01				
		½–3	5.69±.06	5.68±.02	−.01						
		3–7	5.56±.01	5.58±.04	+.02						
		7–12	5.74±.02	5.80±.00	+.06						
		12–16	6.02±.05	6.04±.01	+.02						
		16–20	6.03±.04	6.06±.03	+.03						
		20–24	6.05±.05	6.05±.02	.00						
		24–28	6.03±.04	6.05±.02	+.02						
		28–32	6.39±.08	6.40±.00	+.01						
		32–36	6.38±.03	6.37±.05	−.01						
		36–40	6.39±.04	6.41±.01	+.02						
		40–44	6.39±.04	6.42±.01	+.03						
		44–48	6.50±.03	6.48±.01	−.02						
Cecil sandy loam [2]	Coosa County, Ala	0–4	5.20±.00	5.21±.02	+.01	5.22±.00	+.02				
		18–22	5.34±.02	5.35±.04	+.01						
		40–44	5.10±.00	5.08±.01	−.02						
		74–78	4.93±.00	4.93±.03	.00						

[1] 8 determinations were made of each sample in each condition.
[2] 4 determinations were made of each sample in each condition.

TABLE 13.—*Hydrogen-ion determinations of lateritic soils taken in the moist field condition and in the air-dry state and the effects of restorative treatments on the pH of some of the air-dried samples*—Continued

Soil type	Location	Depth	Moist field sample	Air-dry sample	Change from moist field condition	Air-dry soil in contact with water 18–24 hours	Change from moist field condition	Air-dry soil moistened 4–7 days before	Change from moist field condition	Air-dry soil moistened 30 days before	Change from moist field condition
		Inches	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Decatur silty clay loam [2]	Coosa County, Ala.	0–4	5.91± .01	5.89± .00	−.02	5.84± .01	−.07				
		30–34	5.19± .01	5.21± .01	+.02						
		44–48	4.95± .02	4.92± .03	−.03						
Madison gravelly loam [2]	do	0–4	4.87± .03	4.91± .02	+.04	4.84± .01	−.03				
		12–16	5.00± .00	5.05± .02	+.05						
		26–30	5.17± .00	5.20± .02	+.03						
		40–44	5.19± .01	5.20± .02	+.01						
Aiken clay loam [2 3]	Columbia County, Oreg.	0–2	5.60± .01	5.56± .01	−.04	5.56± .03	−.04	5.68± .01	+.08		
		7–11	5.43± .02	5.46± .01	+.03						
		24–28	5.40± .00	5.42± .03	+.02						
		66–70	5.40±. 00	5.39± .00	−.01						
Aiken clay loam [2 3]	Placer County, Calif.	0–4	5.80± .00	5.50± .03	−.30	5.81± .04	+.01	5.45± .00	−.35	5.25± .00	−.55
		4–20	5.90± .00	5.75± .00	−.15	5.90± .00	+.00	5.84± .02	−.06	5.69± .00	−.21
		20–36	5.44± .01	5.45± .02	+.01						

[2] 4 determinations were made of each sample in each condition.

[3] Humid red soil which probably is lateritic.

Three profiles (11 horizon samples) of imperfectly drained soils of lateritic regions were examined (Table 14). Of these, but one horizon, the surface layer of the Appling sandy loam profile, changed more than 0.10 pH unit on drying. It became 0.22 pH unit more acid.

TABLE 14.—*Hydrogen-ion determinations of imperfectly* [1] *drained soils of lateritic regions taken in the moist field condition and in the air-dry state and the effects of restorative treatments on the pH of some of the air-dried samples* [2]

Soil type	Location	Depth	Moist field sample	Air-dry sample	Change from moist field condition	Air-dry soil in contact with water 18–24 hours	Change from moist field condition	Air-dry soil moistened 4–7 days before	Change from moist field condition	Air-dry soil moistened 30 days before	Change from moist field condition
		Inches	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Irvington very fine sandy loam	Mobile County, Ala.	0–1½	5.41±0.08	5.42±0.03	+0.01	5.37±0.05	−0.04				
		4–8	5.29±.06	5.33±.00	+.04						
		12–16	5.23±.07	5.23±.09	.00						
		26–30	5.18±.05	5.22±.01	+.04						
Norfolk fine sandy loam	do	0–1½	5.44±.01	5.43±.00	−.01	5.43±.00	−.01				
		3–7	5.23±.00	5.21±.01	−.02						
		15–19	5.02±.03	5.03±.02	+.01						
		29–33	5.11±.01	5.05±.00	−.06						
Appling sandy loam	Coosa County, Ala.	0–4	5.50±.02	5.28±.04	−.22	5.47±.02	−.03	5.52±.03	+0.02	4.87±.00	−0.63
		18–22	5.26±.01	5.23±.01	−.03						
		22–36	4.92±.01	4.98±.01	+.06						

[1] These soils are sufficiently well drained for agricultural purposes.
[2] 4 determinations were made of each sample in each condition.

Four immature profiles (15 horizon samples) were studied (Table 15). Of these the profile of Mucara clay from Porto Rico altered on drying between 0.10 and 0.20 pH unit in the upper four of its five horizons.

TABLE 15.—*Hydrogen-ion determinations of immature soils taken in the moist field condition and in the air-dry state, and the effects of restorative treatments on the pH of some of the air-dried samples* [1]

Soil type	Location	Depth	Moist field sample	Air-dry sample	Change from moist field condition	Air-dry soil in contact with water 18–24 hours	Change from moist field condition	Air-dry soil moistened 4–7 days before	Change from moist field condition	Air-dry soil moistened 30 days before	Change from moist field condition
		Inches	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Houston clay [2]	Montgomery County, Ala.	0–9	8.00±0.03	8.00±0.03	0	8.00±0.03	0				
		9–35	8.13± .02	8.10± .05	−.03						
		35–50	8.17± .02	8.17± .03	.00						
Mucara clay	San Juan area, Porto Rico	0–1	6.58± .02	6.45± .05	−.13	6.61± .04	+.03	6.33±0.00	−0.25	6.16±0.03	−0.42
		1–10	6.77± .03	6.61± .04	−.16	6.74± .01	−.03	6.81± .08	+.04	6.82± .00	+.05
		10–24	6.71± .06	6.57± .08	−.14	6.71± .04	.00	6.72± .10	+.01	6.82± .02	+.11
		24–30	6.89± .03	6.69± .04	−.20	6.87± .05	−.02	6.85± .05	−.04	6.76± .03	−.13
		30–48	7.39± .06	7.36± .03	−.03						
Lehew gravelly silt loam	Tioga County, Pa.	0–2	4.76± .06	4.77± .00	+.01	4.81± .01	+.05	5.11± .01	+.35		
		2–12	5.15± .02	5.13± .00	−.02						
		12–24	5.13± .02	5.11± .01	−.02						
Elkhorn loamy fine sand [3]	Oceanside area, California	0–¼	7.11± .08	7.10± .09	−.01	7.20± .02	+.09				
		6–10	6.51± .02	6.53± .06	+.02						
		24–28	7.47± .05	7.45± .03	−.02						
		60–64	7.89± .03	7.83± .02	−.06						

[1] 8 determinations were made of each sample in each condition. [2] Rendzina. [3] Bordering on reddish-brown pedocals.

Both restorative treatments were employed on the horizons of the three soil groups which had changed more than 0.10 pH unit on air drying. (Tables 12–15.) All these horizon samples were restored to within the above deviation from the original pH values by submergence in water from 18 to 24 hours. On the other hand, moistening the same samples and keeping them moist from 4 to 7 days failed to restore the original pH value of the moist sample in the case of the reddish-brown pedocal humus horizon sample (note 7, Table 12) in 2 of the 3 horizon samples of the lateritic soils and in 1 of the 4 horizons of the immature soils. In the other samples both treatments were effective. This clearly shows that the first treatment is the better one for these soils. In one case (Table 13) the surface horizon became 0.33 pH unit less acid on standing for 7 days in the moist condition, but at the end of 30 days' storage it returned to its original pH value. Two other moistened horizons (Table 15) became slightly less acid on storage and a surface sample (Table 15) which had changed less than 0.10 pH unit on drying became 0.35 pH unit less acid 7 days after being moistened. This behavior is in contrast with the results shown by Teräsvuori (*40*) (Table 8) and similar to those of Achromeiko (*2*) (Tables 1 and 2). In contrast with these samples the remainder of the horizon samples became more acid as a result of storage in the moist condition as found by Teräsvuori (*40*) (Table 8) and Rost and Fieger (*36*). One sample (footnote 7, Table 12) became 1.31 pH unit more acid than the original moist sample following 30 days of storage in the moist condition.

A check on the restorative treatment by submergence from 18 to 24 hours in distilled water was obtained by using it on 16 upper horizon samples from the brownish-red profiles bordering on pedocals (Table 11) from the lateritic soils (Table 13), from the imperfectly drained soils from lateritic regions (Table 14), and from the immature profiles (Table 15), which had not altered more than 0.10 pH unit on drying. In every case the values obtained did not vary from that of the original moist sample by more than this value.

The horizons, appreciably changed by air drying, which responded best to the treatment of being moistened and stored in a moist condition from four to seven days were from the podsol group (Table 16), from the degraded chernozems (Table 17), and from the podsolic profiles of the Pacific coast (Table 18).

TABLE 16.—*Hydrogen-ion determinations of podsol soils taken in the moist field condition and in the air-dry state and the effects of restorative treatments on the pH of some of the air-dried samples*

Soil type	Location	Horizon	Depth	Moist field sample	Air-dry sample	Change from moist field condition	Air-dry soil in contact with water 18–24 hours	Change from moist field condition	Air-dry soil moistened 4–7 days before	Change from moist field condition	Air-dry soil moistened 30 days before	Change from moist field condition
			Inches	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Fine sandy loam [1]	Montreal Island, Quebec, Canada.	Gray-brown humus	0–3	5.13±0.02	4.73±0.06	−0.40	4.89±0.04	−0.24	5.13±0.03	0	4.75±0.05	−0.38
		Black humus	3–4	4.34±.01	4.22±.07	−.12	4.26±.04	−.08	4.33±.03	−.01	4.46±.03	+.12
		Dark-gray layer	4–6	4.45±.02	4.33±.06	−.12	4.41±.04	−.04	4.45±.00	0	4.67±.00	+.22
		Brown	6–11	5.12±.02	5.12±.02	0						
		Reddish brown	11–16	5.69±.02	5.70±.00	+.01						
		Parent material	16–28	6.94±.01	6.92±.02	−.02						
Do.[1]	Compton County, Quebec, Canada.	Raw humus	0–2	5.60±.03	5.65±.02	+.05						
		Gray	2–3	5.16±.03	5.03±.01	−.10	5.06±.01	−.10	5.20±.02	+.04	5.34±.01	+.18
		Brown	3–4	4.70±.01	4.67±.00	−.03						
		Light brown	7–11	4.89±.00	4.91±.01	+.02						
		Parent material	20–24	5.07±.02	5.07±.02	0						
Do.[1]	Brome County, Quebec, Canada.	Raw humus	0–1½	4.72±.02	4.24±.01	−.48	4.36±.01	−.36	4.75±.03	+.03	4.76±.06	+.04
		Gray	1½–3	4.80±.01	4.59±.01	−.21	4.79±.00	−.01	4.79±.04	−.01	4.83±.01	+.03
		Dark coffee colored	3–4	4.80±.00	4.31±.01	−.49	4.62±.00	−.18	4.79±.01	−.01	4.84±.02	+.04
		Medium coffee colored	4–8	4.80±.00	4.56±.01	−.24	4.77±.03	−.03	4.78±.03	−.02	4.93±.02	+.13
		Parent material	20–24	4.93±.03	4.93±.03	0	4.94±.04	+.01	4.94±.03	+.01	5.00±.00	+.07
Becket loam [1]	Berkshire County, Mass.	Humus	0–6	4.04±.03	4.04±.02	0						
		Gray	6–11	3.88±.02	3.86±.01	−.02						
		Brown	11–24	4.16±.04	4.22±.00	+.06						
		Parent material	24–36	4.64±.04	4.63±.03	−.01						
Berkshire loam [1]	Hampshire County, Mass.	Humus	0–2	4.60±.02	4.11±.02	−.49	4.20±.00	−.40	4.59±.02	−.01	5.02±.02	+.42
		Gray	2–3	3.87±.05	3.79±.03	−.08	3.86±.01	−.01	3.91±.02	+.04	4.14±.05	+.27
		Dark coffee colored	3–5	4.10±.02	4.11±.01	+.01	4.01±.02	−.09	4.15±.02	+.05	4.57±.05	+.47
		Medium coffee colored	5–12	4.59±.04	4.59±.00	0	4.62±.00	+.03	4.60±.01	+.01	4.85±.00	+.26
		Light coffee colored	12–20	4.66±.03	4.67±.00	+.01	4.66±.03	0	4.70±.05	+.04	4.88±.05	+.22
		Parent material	20–36	4.87±.02	4.90±.02	+.03						
Becket fine sandy loam [2]	Windham County, Vt.	Humus	0–3	4.03±.00	4.03±.00	0	4.03±.00	0	4.08±.02	+.05	4.36±.03	+.33
		Coffee colored	3–11	4.45±.02	4.48±.03	+.03	4.48±.01	+.03	4.47±.02	+.02	4.82±.00	+.37
		Parent material	48–60	5.05±.00	5.02±.01	−.03	5.05±.00	0	5.06±.01	+.01	5.29±.00	+.24
Hermon fine sandy loam [2]	Rutland County, Vt.	Humus	0–2	4.07±.04	4.00±.01	−.07	4.02±.01	−.05	4.00±.00	−.07	4.76±.03	+.69
		Gray	2–4	4.07±.00	3.77±.00	−.30	4.03±.00	−.04	4.03±.00	−.04	4.03±.00	−.04
		Dark coffee colored	4–6	4.00±.00	3.91±.01	−.09	4.02±.00	+.02	4.03±.03	+.03	4.21±.01	+.21
		Medium coffee colored	6–11	4.19±.00	4.25±.00	+.06	4.22±.03	+.03	4.18±.02	−.01	4.73±.01	+.54
		Parent material	60–72	5.05±.00	5.01±.02	−.04	5.13±.00	+.08	5.05+.02	0	5.32±.00	+.27

Bath gravelly silt loam[2]	Tioga County, Pa.	Humus	0–2	4.85±.05	4.72±.01	−.13	4.71±.01	−.14	4.80±.00	−.05	5.18±.03	+.33
		Gray	2–5	4.80±.03	4.59±.00	−.21	4.72±.00	−.08	4.80±.03	0.00	4.86±.03	+.06
		Brown	5–8	4.08±.01	4.10±.00	+.02	4.08±.02	0	4.12±.00	+.04	4.37±.02	+.29
		Parent material	8–36	4.37±.05	4.39±.00	+.02	4.39±.00	+.02				
Leetonia stony loam [2]	do	Humus	0–2	4.41±.04	4.37±.02	−.04	4.39±.00	−.02	4.45±.05	+.04	4.73±.04	+.32
		Gray	2–5	4.52±.02	4.49±.00	−.03	4.51±.02	−.01	4.48±.01	−.04	4.53±.00	+.01
		Brown	5–10	4.18±.02	4.19±.00	+.01	4.23±.02	+.05	4.21±.01	+.03	4.61±.04	+.43
		Parent material	10–30	4.54±.04	4.53±.00	−.01						
Munising sandy loam [1]	Alger County, Mich.	Humus	0–2	4.56±.07	4.30±.03	−.26	4.16±.02	−.40	4.60±.03	+.04	5.21±.11	+.65
		Gray	2–8	4.69±.06	4.74±.05	+.05						
		Brown	8–24	4.45±.06	4.50±.05	+.05						
		Parent material	24–40	5.09±.09	5.09±.04	0						
		do	40–60	4.78±.05	4.85±.05	+.07						
		do	60–64	4.75±.05	4.79±.01	+.04						
Hiawatha loamy sand [1]	do	Humus	0–3	5.19±.06	5.10±.12	−.09						
		Gray	3–12	4.80±.07	4.78±.08	−.02						
		Brown	12–30	4.61±.08	4.71±.09	+.10						
		Parent material	30–48	4.70±.08	4.75±.05	+.05						
Omega sand [1]	Bayfield County, Wis.	Humus	0–3	4.69±.04	4.68±.01	−.01						
		Gray	3–8	4.93±.05	4.79±.00	−.14	4.62±.01	−.31	4.97±.01	+.04	4.95±.05	+.02
		Brown	12–30	5.45±.02	5.43±.04	−.02						
		Parent material	30–40	5.40±.05	5.45±.02	+.05						

[1] 8 determinations were made of each sample in each condition.

[2] 4 determinations were made of each sample in each condition.

TABLE 17.—*Hydrogen-ion determinations of degraded chernozem [1] soils taken in the moist field condition and in the air-dry state and the effects of restorative treatments on the pH of some of the air-dried samples [2]*

Soil type	Location	Horizon	Depth	Moist field sample	Air-dry sample	Change from moist field condition	Air-dry soil in contact with water 18–24 hours	Change from moist field condition	Air-dry soil moistened 4–7 days before	Change from moist field condition	Air-dry soil moistened 30 days before	Change from moist field condition
			Inches	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Silt loam	Alberta, Canada	Raw humus	0–1½	7.25±0.02	7.23±0.01	−0.02						
		Medium gray	1½–6	5.47± .02	4.96± .00	−.51	5.31±0.02	−0.16	5.45±0.00	−0.02	5.46±0.01	−.01
		Light gray	6–10	5.41± .04	4.96± .00	−.45	5.13± .01	−.28	5.42± .03	+.01	5.40± .00	−.01
		Light brownish gray	18–22	5.03± .09	4.87± .00	−.16	5.06± .01	+.03	5.04± .02	+.01	5.02± .08	−.01
		Medium brownish gray	23–27	5.05± .05	5.03± .03	−.02						
		do	36–40	7.93± .04	7.92± .02	−.01						
		Medium brownish gray with lime concretions.	46–50	8.10± .05	8.10± .03	−.00						
		Medium brownish gray with no lime concretions.	70–74	8.09± .06	8.10± .05	+.01						
Loam	do	Raw humus	0–2½	6.33± .01	6.38± .03	+.05						
		Dark brown	2½–6	7.30± .03	7.29± .03	−.01						
		Light gray	8–12	7.42± .09	7.41± .06	−.01	7.36± .04	−.06	7.46± .03	+.04	6.90± .13	−.52
		Light brownish gray	15–19	5.19± .06	5.18± .03	−.01	5.27± .02	+.08	5.18± .05	−.01	5.17± .00	−.02
		Medium brownish gray	40–44	5.67± .07	5.69± .04	+.02						
		Dark brownish gray	58–62	7.98± .06	7.99± .03	+.01						
		Dark brownish gray containing lime concretions.	70–74	8.20± .07	8.18± .07	−.02						

[1] These soils differ from the true podsols in having the brown color very weakly developed in the B horizon.
[2] 8 determinations were made of each sample in each condition.

TABLE 18.—*Hydrogen-ion determinations of podsolic soils of the Pacific coast taken in the moist, field condition and in the air-dry state and the effects of restorative treatments on the pH of some of the air-dried samples* [1]

Soil type	Location	Depth	Moist field sample	Air-dry sample	Change from moist field condition	Air-dry soil in contact with water 18–24 hours	Change from moist field condition	Air-dry soil moistened 4–7 days before	Change from moist field condition	Air-dry soil moistened 30 days before	Change from moist field condition
		Inches	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Cascade silt loam	Columbia County, Oreg.	0–2½	5.16±0.03	4.78±0.01	−0.38	4.86±0.03	−0.30	5.16±0.03	0	4.94±0.04	−0.22
		8–12	5.91± .01	5.23± .02	−.68	5.48± .01	−.43	5.86± .05	−.05	5.42± .00	−.49
		20–24	5.88± .01	5.55 ±.00	−.33	5.78± .01	−.10	5.90± .01	+.02	5.90± .00	+.02
		40–44	6.02± .01	5.99± .03	−.03						
		60–64	5.59± .01	5.59± .04	.00						
Willamette loam	do	0–2½	5.25± .02	5.19± .01	−.06	5.20± .00	−.05	5.26± .03	+.01		
		6–10	5.50± .02	5.26± .01	−.24	5.31± .01	−.19	5.50± .02	0	5.53± .02	+.03
		21–25	5.48± .01	5.45± .02	−.03						
		57–61	5.70± .00	5.52± .05	−.18	5.69± .01	−.01	5.67± .05	−.03		
		96–100	6.15± .02	5.79± .01	−.36	5.65± .00	−.50	6.14± .01	−.01	6.16± .03	+.01

[1] 4 determinations were made of each sample in each condition.

Twelve podsol profiles (56 horizon samples) were examined (Table 16). Thirteen horizon samples from seven of the profiles became more than 0.10 pH unit more acid on air drying. Nine changed more than 0.20 pH unit. The greatest difference between the moist and the air-dry samples was 0.49 pH unit. With only three exceptions (podsol layers) the greatest change took place in the humus and in the coffee-colored layers. In most cases the humus horizons showed more change than did the coffee-colored layers.

Two degraded chernozem profiles (15 horizon samples) were studied (Table 17). Three horizon samples from one of the profiles showed a change of more than 0.10 pH unit on air drying. Unlike the podsol group, the three layers that changed appreciably in this group were all from the gray layers. One sample from the upper gray horizon changed as much as 0.51 pH unit.

Two podsolic profiles of the Pacific coast (10 horizon samples) were studied (Table 18). Six horizon samples (three from each profile) changed more than 0.10 pH unit and five more than 0.20 pH unit on passing from the moist to the air-dry condition. The horizon from 8 to 12 inches, just below the one high in organic matter from the Cascade silt loam profile became 0.68 pH unit more acid. As has already been pointed out, that was the greatest change made by any of the 327 horizon samples on becoming air-dry. One profile, that of the Cascade silt loam, showed the greatest changes in the upper horizons, whereas the other profile, that of the Willamette loam, showed the greatest changes in the lower layers.

Both restorative treatments were likewise used on the horizons of the last three soil groups which had changed more than 0.10 pH unit on drying. (Tables 16–18.) All these horizon samples were restored to within the above variation from the fresh, moist samples by moistening and keeping them moist from four to seven days. But submerging these same samples in water from 18 to 24 hours failed to restore, within 0.10 pH unit, the value of the original moist sample in 7 of the 13 podsol horizon samples, in 2 of the 3 degraded chernozem horizons, and in 4 of the 6 horizon samples of the podsolic profiles of the Pacific coast. In the other cases both treatments were effective. This clearly shows that the former restorative treatment is the better one for these soils. Care has to be taken, however, not to moisten the soils much longer than a week before making the determinations or to allow the room temperature to get much above 25° C. after they are moistened. Otherwise the samples are likely to become considerably less acid in the podsol group and more acid in the degraded chernozems and in the podsolic soils of the Pacific coast. This change in reaction on storage in a moist condition and at temperatures above 25° C. is doubtless due to biological activity. Robinson (*35*) reports that soils on storage in a water-logged condition become considerably less acid.

As a check on these two restorative treatments, 20 horizon samples from the humus, podsol, and coffee-colored layers of these groups that had not changed appreciably on air drying were subjected to both treatments. All these check samples remained within 0.10 pH unit of the original moist samples following both treatments.

Some of the horizons of the podsolic soils of the Eastern and Midwestern States that changed more than 0.10 pH unit on drying responded better to one restorative treatment, whereas others were better restored to the pH values of the original moist samples by the other restorative treatment. Thirteen representative profiles (73 horizon samples) of this group were studied (Table 19).

TABLE 19.—*Hydrogen-ion determinations of podsolic soils of the Eastern and Midwestern States taken in the moist, field condition and in the air-dry state and the effects of restorative treatments on the pH of some of the air-dried samples*

Soil type	Location	Depth	Moist field sample	Air-dry sample	Change from moist field condition	Air-dry soil in contact with water 18–24 hours	Change from moist field condition	Air-dry soil moistened 4–7 days before	Change from moist field condition	Air-dry soil moistened 30 days before	Change from moist field condition
		Inches	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Merrimac sandy loam [1]	Hampshire County, Mass.	0–1	4.34±0.05	4.09±0.01	−0.25	4.07±0.02	−0.27	4.39±0.00	+0.05	4.89±0.00	+0.55
		1–5	4.54± .01	4.52± .00	−.02						
		5–15	5.43± .06	5.39± .02	−.04						
		15–24	5.57± .02	5.55± .02	−.02						
		24–36	5.86± .03	5.85± .02	−.01						
Gloucester loam [1]	do	0–2	4.16± .07	3.85± .02	−.31	3.90± .03	−.26	4.17± .02	+.01	4.71± .02	+.55
		2–6	4.38± .01	4.27± .02	−.11	4.38± .03	.00	4.67± .05	+.29	5.16± .03	+.78
		6–15	5.06± .04	4.79± .00	−.27	4.99± .04	−.07	5.09± .01	+.03	5.31± .01	+.25
		15–24	5.86± .03	5.69± .02	−.17	5.85± .03	−.01	5.88± .03	+.02	6.09+ .01	+.23
		24–36	5.99± .00	5.79± .00	−.20	5.97± .01	−.02	5.98± .02	−.01	6.07± .02	+.08
Volusia gravelly silt loam [2 3]	Tioga County, Pa.	0–6	4.71± .01	4.78± .01	+.07	4.92± .02	+.21	5.07± .02	+.36	5.16± .01	+.45
		6–10	4.73± .03	4.72± .00	−.01						
		10–15	4.77± .02	4.77± .00	0						
		15–30	5.17± .00	5.17± .00	0						
		72–76	7.98± .02	7.92± .02	−.06						
Chester loam [4]	Fairfax County, Va.	0–¼	7.09± .13	7.11± .08	+.02	7.13± .04	+.04	7.20± .00	+.11		
		¼–3	6.50± .07	6.52± .13	+.02						
		3–8	5.55± .05	5.52± .05	−.03						
		8–25	5.35± .12	5.43± .04	+.08						
		25–35	5.44± .13	5.48± .05	+.04						
		35–48	5.35± .05	5.28± .14	−.07						
		48–60	5.37± .07	5.30± .12	−.07						
Chester loam (claypan phase) [4 3]	do	0–¼	5.36± .06	5.46± .04	+.10	5.35± .01	−.01	5.78± .05	+.42		
		¼–3	4.71± .09	4.79± .11	+.08						
		3–30	4.85± .05	4.83± .07	−.02						
		30–40	4.94± .06	4.85± .07	−.09						
		40–48	4.94± .06	4.84± .09	+.10						
Collington fine sandy loam [1]	Anne Arundel County, Md.	0–½	4.14± .04	4.16± .04	+.02	4.08± .03	−0.06	4.52+ .00	−.38		
		2–5	4.44± .08	4.45± .05	+.01						
		6–10	4.91+ .14	4.94± .04	+.03						
		14–18	4.99± .11	4.98± .02	−.01						
		21–25	4.63± .06	4.63± .03	0						
		29–33	4.76± .07	4.77± .02	+.01						
		39–43	4.72± .12	4.71± .08	−.01						
		58–62	4.61± .11	4.62± .00	+.01						

Sassafras fine sandy loam [1]	do	0–1	5.49± .06	5.08± .05	−.41	5.31± .11	−.18	5.55± .02	+.03	5.76± .04	+.27
		1–4	5.34± .02	4.34± .01	0						
		8–12	4.70± .03	4.68± .03	−.02						
		18–22	4.51± .01	4.51± .02	0						
		32–36	4.45± .02	4.45± .03	0						
		49–53	4.39± .04	4.39± .03	0						
		68–72	4.34± .05	4.37± .00	+.03						
Alexandria silt loam [1]	Licking County, Ohio	0–4	5.20± .05	5.18± .01	−.02	5.17± .00	−.03	5.55± .00	+.35		
		6–10	4.64± .05	4.66± .04	+.02						
		17–21	4.99± .05	4.98± .02	−.01						
		38–42	8.34± .09	8.27± .04	−.07						
Bennington silt loam [1 3]	do	0–1	5.83± .06	5.46± .03	−.37	5.83± .06	0.00	6.06± .03	+.23	5.76± .03	−.07
		2–5	5.02± .05	4.90± .05	−.12	5.03± .04	+.01	5.06± .03	+.04	5.30± .00	+.28
		7–10	4.72± .07	4.71± .01	−.01						
		13–17	4.75± .05	4.80± .03	+.05						
		40–44	8.51± .08	4.47± .04	−.04						
Miami silt loam [1]	Rush County, Ind	0–2	5.72± .07	5.74± .06	+.02	5.80± .00	+.08	6.03± .00	+.31		
		2–12	5.85± .02	5.87± .03	+.02						
		12–20	5.63± .07	5.62± .05	−.01						
		20–28	5.03± .06	5.04± .03	+.01						
		28–32	7.23± .10	7.22± .05	−.01						
		32–45+	8.51± .08	8.48± .05	−.03						
Russell silt loam [1]	do	0–2	5.73± .06	5.74± .05	+.01	5.74± .01	+.01	5.79± .03	+.06		
		2–12	4.30± .03	4.28± .05	−.02						
		12–20	4.64± .07	4.66± .04	+.02						
		20–40	4.71± .09	4.73± .01	+.02						
		40–52	7.35± .04	7.36± .04	+.01						
		52–60+	8.15± .12	8.18± .08	+.03						
Clinton silt loam [2]	Vernon County, Wis	0–2	5.37± .03	5.47± .02	+.10						
		2–3	5.65± .03	5.66± .03	+.01						
		3–13	5.80± .03	5.85± .04	+.05						
		13–20	5.20± .03	5.17± .02	−.03						
		20–28	5.05± .03	5.07± .02	+.02						
		28–32	5.00± .01	5.07± .02	+.07						
Boone silt loam [2]	do	0–4	4.86± .03	4.91± .01	+.05	4.90± .03	+.04	5.18± .01	+.32		
		4–14	5.91± .01	5.92± .03	+.01						
		14–20	5.11± .01	5.34± .04	+.23	5.11± .02	.00	5.11± .02	.00	5.11± .02	.00
		20–32	5.16± .03	5.39± .00	+.23	5.13± .03	−.03	5.13± .00	−.03	5.13± .00	−.03

[1] 8 determinations were made of each sample in each condition.
[2] 4 determinations were made of each sample in each condition.
[3] Imperfectly drained soils.
[4] 18 determinations were made of each sample in each condition.

Eleven horizon samples from 5 of these profiles changed more than 0.10 pH unit on air drying and 8 horizon samples changed 0.20 pH unit and more. The greatest change was in the humus layer of the Sassafras fine sandy loam from Anne Arundel County, Md., which became 0.41 pH unit more acid. With the exception of its organic layer the Gloucester loam profile from Hampshire County, Mass., showed the greatest change on air drying in its deeper horizons, and the Boone silt loam profile from Vernon County, Wis., showed a change of 0.23 pH unit in both of its deepest layers and none in its leaf-mold horizon. With these exceptions practically all the change took place in the upper humus layers. The two lower horizons from the Boone silt loam profile became less acid. Of the total number of horizon samples from all the groups examined, which changed more than 0.10 pH unit on drying, these were the only ones that became less acid.

Both restorative treatments were also employed on the 11 horizons of the foregoing group which had changed more than 0.10 pH unit on drying. (Table 19.) Six of these were restored by either treatment, 2 responded only to submergence in water from 18 to 24 hours, and 3 responded only to being moistened and stored in a moist condition from 4 to 7 days. These last three samples were the humus layers of the Gloucester loam and the Merrimac sandy loam profiles of Hampshire County, Mass., and the humus horizon of the Sassafras fine sandy loam profile from Anne Arundel County, Md. These three leaf-mold layers all resembled the raw humus horizons of the podsol profiles in their physical appearance. Therefore, the general statement may be made that the horizon samples of the podsolic soils from the Eastern and Midwestern States which have changed more than 0.10 pH unit on air drying are best restored to the approximate pH value of the original moist samples by submergence in water from 18 to 24 hours, unless they resemble the raw humus layers of the podsols in physical appearance, in which case moistening and storing them while moist from 4 to 7 days appears to be the better treatment.

Seven of these 11 horizon samples became distinctly less acid after 30 days' storage in a moist condition. This agrees with the results obtained with the podsols (Table 16), but disagrees for the most part with those obtained with the brownish-red soils bordering on the pedocals, the reddish-brown pedocal humus layer, the lateritic soils, the imperfectly drained soils of lateritic regions, the immature soils, the degraded chernozems, and the podsolic soils of the Pacific coast (Tables 11–15, 17, and 18.)

As a check on these two treatments 8 surface horizons that had not changed appreciably on air drying were given both of these treatments. Seven of the 8 samples remained within 0.10 pH unit of the fresh moist samples after submergence in water from 18 to 24 hours; only 1 sample remained within that degree of variation from the original moist sample after being moistened and stored in a moist condition from 4 to 7 days. Only 1 of the 8 check surface horizon samples varied more than 0.10 pH unit from the fresh moist sample by being submerged in water from 18 to 24 hours. This one exception was the 6-inch surface layer from the Volusia gravelly silt loam profile from Tioga County, Pa. It became 0.21 pH unit less acid following that treatment and became 0.36 pH unit less acid after being moistened and stored in that condition from four to seven days.

DISCUSSION

The easy restoration of the air-dried samples to approximately their original pH values by using one or the other of the restorative treatments indicates that the changes induced by drying are readily reversible. The soil samples from the podsols, degraded chernozems, and podsolic soils from the Pacific coast, which altered most on air drying, were the ones that required moistening with distilled water from 4 to 7 days before making the determinations, and the soil samples from the other groups which made less change on drying responded better, for the most part, to being submerged in distilled water from 18 to 24 hours.

In order to explain the changes in reaction of the soil samples on air drying and the restorative effects of the treatments it will be necessary to review briefly the causes of soil acidity. Soils in humid climates have a strong tendency to become acid. Several factors operate in producing this condition. One of the most important is the production of soluble organic acids, particularly of carbonic acid which is abundantly formed through the action of various living organisms on plant remains. This acid forms relatively soluble carbonates and bicarbonates with the bases which are in combination with the relatively insoluble organic and mineral acids. The bases are thus leached away, leaving the insoluble material in a more or less unsaturated condition with respect to bases. This is especially true in the podsol soils.

Soil acids appear to consist largely of compounds of very low solubility. The pH values of such compounds where determined by the hydrogen electrode may be considerably influenced by the presence of the suspended solid material in contact with the electrode. It is for this reason that the soil particles must be kept in as complete agitation as possible when making a hydrogen-ion determination in order to bring the greatest number of soil particles in actual contact with the hydrogen electrode and thereby obtain a measurement of the influence of the almost insoluble acid constituents (*9, 17, 19, 21, 33, 36, 38*).

As has already been brought out, the greatest changes on air drying in these investigations took place in the upper layers of high organic-matter content. As has also been shown, only 1 sample of the entire 327 horizon samples studied, a surface sample high in humus, which changed more than 0.10 pH unit on becoming air-dry (Table 12), was above neutral in reaction. These two facts show that changes in pH values of soil samples on drying occur mostly in samples high in organic matter that is unsaturated with bases as indicated by the pH values. This explains why the podsols showed such a strong tendency to change in their organic matter layers on becoming air-dry. (Table 16.) Knickmann (*26*) and Achromeiko (*2*) are both emphatic in attributing the changes in reaction produced by drying soils to the presence of organic matter. Both worked on acid soils. Knickmann states that the increase in acidity of a soil sample on drying is proportional to its organic-matter content. Tables 20 and 21 from Achromeiko's work indicate his conclusions on this subject.

TABLE 20.—*Amount of water-soluble organic matter in 1 liter of extract from the surface 3 inches of a podsolic soil from an uncultivated field of the Agricultural Academy, Moscow, Russia, after several different treatments* [1]

[Expressed in millograms of oxygen [2]]

Treatment of sample	Before capillary moistening	After capillary moistening for—					
		3 days	7 days	21 days	45 days	90 days	210 days
Crumbed soil, fresh moist	43.9	43.0	40.6	33.0	28.1	26.2	24.3
Crumbed soil, dried in sun	230.0	151.2	89.3	62.5	53.1	39.2	36.1
Crumbed soil, dried in oven at 100° C. for 36 hours	845.0	633.0	402.0	290.0	195.0	140.0	----

[1] Data from Achromeiko (*2*) on Russian soils.
[2] Determined by oxidation with potassium permanganate.

The effect on the solubility of organic matter that Achromeiko obtained by drying the same podsolic surface soil, shown in Table 1, in the sun and in the oven at 100° C., together with the effects of various restorative treatments, is shown in Table 20. It is not clear to the author whether Achromeiko meant a true solution of the organic matter or merely a colloidal solution. More than five times as much organic matter went into solution after the sample had been dried in the sun than from the fresh, moist sample, and drying the sample in the oven at 100° increased the solubility of the organic matter more than nineteenfold. The humus of the moist samples when stored at room temperatures became increasingly less soluble until, at the end of 210 days, just a little more than half as much organic matter was taken into solution as in the fresh, moist sample. Likewise the humus in the samples dried in the sun and in the oven at 100°, when moistened became less soluble as the days passed. The solubility of the organic matter in the sun-dried sample was reduced to the same solubility of that in the fresh, moist sample from 45 to 90 days after moistening, and the solubility of the humus in the sample dried at 100° was reduced after 90 days of storage in a moistened condition from nearly nineteen times to a little more than three times that of the original moist sample. Table 1 shows that the pH value of this same soil was restored to the approximate pH value of the fresh moist sample, both when dried in the sun and when dried at 100°, between three and seven days after moistening. In the same period of time the organic matter in the sun-dried sample was still two to more than three times as soluble as that in the original moist sample, and the solubility of the humus in the oven-dried sample was from nine to more than fourteen times greater than the solubility of the organic matter in the fresh, moist sample. This would indicate that there were other factors operating in the change of pH of the soil sample and in its restoration following moistening and storage besides the mere solubility of the organic matter.

TABLE 21.—*Amount of dispersed particles* [1] *in the suspension in grams from 1 kilogram absolutely dry soil of the surface 3 inches of a podsolic soil from an uncultivated field of the Agricultural Academy, Moscow, Russia, after several different treatments* [2]

[Size of particles<0.001 mm.]

Treatment of soil sample	Precipitate after 24 hours—								
	Without capillary moistening			After capillary moistening					
				7 days			21 days		
	Organic matter	Mineral matter	Total	Organic matter	Mineral matter	Total	Organic matter	Mineral matter	Total
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Crumbed soil, fresh moist	0.84	3.92	4.76	0.73	3.48	4.21	0.87	4.01	4.88
Crumbed soil, dried in sun	1.28	2.02	3.30	1.00	3.06	4.06	1.03	3.90	4.93
Crumbed soil, dried in oven at 100° C.	3.27	1.88	5.15	2.01	3.00	5.01	1.42	3.86	5.28

[1] Robinson's method.
[2] Data from Achromeiko (*2*) on Russian soils.

Achromeiko shows (Table 21) the effect of drying the same soil in the sun and in the oven at 100° C. on the dispersion of its organic and its mineral matter. He also shows the effect of moistening these dried samples and storing them at room temperatures for different lengths of time. The organic matter became more than 50 per cent more easily dispersed and the mineral matter became nearly 50 per cent less easily dispersed on drying the sample in the sun. By drying the sample in the oven at 100° C. the organic matter became nearly four times as easily dispersed and the mineral matter less than half as easily dispersed as in the original moist sample. Moistening and storing the dried samples had a decided tendency toward reversing the effects of drying. But at the end of 7 days of storage in a moist condition the humus was still nearly 20 per cent more dispersed and the mineral matter more than 20 per cent less dispersed in the sun-dried sample than in the fresh, moist soil, and in the oven-dried sample even at the end of 21 days of storage in a moistened condition the organic matter was still nearly 70 per cent more dispersed, but the mineral-matter content had been brought back to almost the same degree of dispersion it had in the original moist soil. Thus the dispersion of the organic matter worked in the same direction as the solubility of the humus on the reaction of the sample following drying and subsequent restorative treatments, whereas the dispersion of the mineral matter appeared to work in the opposite direction. Probably there were other factors operating besides these three.

Achromeiko is not the only investigator who has found that the dispersion of mineral soil particles is decreased by drying. Steenkamp (*39*) found that in using Robinson's method of mechanical analysis without dispersing agents, there was less than half as much clay from the air-dried sample as from the corresponding moist sample. He also found the silt content to be only 79 per cent as high from the air-dry sample, whereas the fine sand content from the air-dry sample was nearly 2½ times as high as from the moist sample. Puri and Keen (*34*) also found that air drying greatly decreases the dispersion

of clay particles due to their becoming cemented together on drying. Anderson and Byers (*3*) found that with electrodialyzed colloids of the major soil groups the clear supernatent liquid from every sample was less acid than was the colloidal suspension. In the former case only the readily water-soluble acidity was being measured, but in the latter case the almost insoluble acidity existing in the mineral colloidal particles was being measured as well as the water-soluble acidity. The writer has also noticed a strong tendency for soil suspensions to become less acid or more alkaline if the soil particles are allowed to settle at the bottom instead of being kept in complete suspension. By combining these facts it can readily be seen that anything such as air drying, which would decrease the dispersion of the mineral soil particles, would have a tendency to cause the soil suspension of the sample to measure less acid or more alkaline. This may be the explanation of the behavior of the two subsoil horizons of the podsolic profile from the Middle West (Table 19) which, having practically no organic matter in them, both became 0.23 pH unit less acid on drying. It may likewise be the reason for the few cases reported by other investigators (*1*, *36*, *40*) of soils becoming less acid or more alkaline on passing from the moist to the air-dry condition.

Another factor in the changes in pH values brought about by air drying may be changes in the exchangeable bases. Steenkamp (*39*) from his work on several English soils found that in three cultivated surface soils the quantity of neutral salt-forming bases such as MgO, K_2O, and Na_2O increased from 11 to 14 per cent on air drying, and the degree of saturation with these bases was also increased 10 or 12 per cent, whereas in the uncultivated pasture soil there was a decrease of 12 per cent in the quantity of neutral salt-forming bases and a decrease of 13 per cent in the degree of saturation with these bases on drying. This uncultivated pasture soil almost doubled its amount of acid salt-forming exchangeable bases on becoming air-dry. Of course the increase in the amount of neutral salt-forming exchangeable bases on drying would make the sample less acid or more alkaline, whereas the increase of the acid salt-forming exchangeable bases would cause the sample to become more acid on passing from the moist to the air-dry condition. As stated before, Coles and Morison (*14*) also studied the effects of air drying on English soils. Most of the samples were taken from uncultivated land either in forest or in pasture. (Table 5.) These writers found that the soils after drying at 98° C., like Steenkamp's uncultivated soil from pasture land, contained a smaller quantity of exchangeable bases than did the moist samples. They concluded that the exchangeable bases must in some way be responsible for the increase in acidity which they found in soil samples on air drying. As all the soils in the investigations recorded in this paper were virgin, they would naturally be more like the uncultivated soils of Steenkamp and of Coles and Morison as to the behavior of their exchangeable bases. The other investigators worked with cultivated as well as with virgin soils, hence the findings of Steenkamp and of Coles and Morison may account for some of their soil samples becoming less acid or more alkaline on drying (*1*, *36*, *40*).

Still another factor which may influence the reactions of soil on air drying and on subsequent restorative treatments is that of solubility. Kelly and McGeorge (*25*) worked on two lateritic surface soils and on one lateritic subsoil from the Hawaiian Islands. Since in the

hydrogen-ion determinations given in this bulletin the water used in the determination stood on the soils from 10 minutes to several hours and one of the restorative treatments was to allow the distilled water to stand on the soils from 18 to 24 hours before making the determinations, for comparative purposes Kelly and McGeorge's findings on subjecting the moist and the air-dried soils to 1-hour extraction with distilled water and 24-hour water extraction of the air-dried samples were selected. From their data the water extract from the first surface-soil sample after 1-hour contact with the soil was slightly less acid after the sample was air-dried than was the same extract when the sample was moist, and the extract following 24-hour contact with the air-dried soil was still less acid. The water extract after 1-hour contact with the air-dried second surface-soil sample was more than twice as acid as that from the moist soil and the 24-hour extract from the moist sample. With the subsoil sample the water extract after 1-hour contact with the air-dried sample was slightly more acid than was the same extract from the moist sample, and the water extract after 24-hour contact with the dried sample was slightly less acid than the 1-hour extract from the moist sample. From Kelly and McGeorge's work it appears that some soils may show a decrease and others an increase in soluble acidity from air drying and that submerging the air-dried soil for 24 hours in distilled water may with some soils increase the soluble acidity and with others decrease it.

It can be readily understood from the discussion of the several factors involved in the changes of reaction brought about by drying soil samples and by the subsequent restorative treatments that they do not all operate in the same direction. These different factors appear to balance each other so that in most cases there is no appreciable change in reaction on air drying. By far the most important factors appear to be the amount of acid organic matter present, its solubility and its dispersion.

Cultivated soils under field conditions appear to show considerable seasonal variation (*6, 10, 12, 15, 16, 24, 27, 29, 31*). Most of the investigators found acid soils to be considerably more acid (0.2 to 2.0 pH units) in late summer and fall than in early spring (*6, 10, 12, 15, 16, 24, 27, 31*). Lipman and his associates (*29*) appear to be the only investigators who found acid soils becoming less acid in the fall than in the spring. They found several that became 0.2 to 0.7 pH unit less acid. Most of the alkaline soils showed very little seasonal variations but some were most erratic (*6, 10, 15, 24*). Baver (*6*) and Kelley (*24*) noticed a tendency for acid soils to increase in hydrogen-ion concentration following a rain. Some of the soils tested by them became from 0.15 to 0.25 pH unit more acid. The seasonal variation in the soil reaction from early spring to late summer and fall is doubtless due to the drying of the soil which causes it to approach an air-dry condition in the later part of the growing season. One would think that with acid soils the reaction would tend to become less acid following a rain but probably some of the factors working in the opposite direction operate more strongly under these conditions. Because of these variations in the hydrogen-ion concentration of soils under field conditions, which appear to be greater than the changes induced by air drying the soil samples, it seems better for comparative purposes to make all hydrogen-ion determinations on air-dry samples rather than to use the moist samples fresh

from the field as some investigators advocate (*1, 6, 11, 19, 26, 36*). As mentioned earlier in this bulletin, air-dry samples are much more convenient to use than are the fresh, moist samples, and it is practically impossible to store samples in a moist condition for any length of time without having their reaction change more or less.

SUMMARY

Three hundred and twenty-seven moist horizon samples from 64 representative virgin profiles from widely scattered parts of the United States, from Porto Rico, and from Canada, were collected in tin cans by field men in the soil survey and by experiment station workers from this country and from Canada and sent to the laboratory. On reaching the laboratory each sample was carefully mixed and from 4 to 18 hydrogen-ion determinations were run on it while it was still in a moist condition. The samples were then air-dried and from 4 to 18 determinations were again made on each.

A bubbling hydrogen electrode method was used in making the hydrogen-ion determinations.

Twenty soil profiles, or 31 per cent of the profiles studied, showed a change of more than 0.10 pH unit on air drying. Forty-two horizon samples or 13 per cent of the total number examined, changed more than 0.10 pH unit. Only 2 of the 64 profiles studied contained horizons that changed 0.50 pH unit or more.

When the change exceeded 0.10 pH unit, it was in the direction of greater acidity, with only two exceptions. With few exceptions the greatest change on drying took place in the layers high in organic matter. With only one exception the horizon samples that changed more than 0.10 pH unit on becoming air-dry were acid in reaction.

None of the humid-prairie profiles, the brownish-red soils bordering on the pedocals, and, with the exception of one surface layer, none of the pedocals consisting of the chernozems, the reddish-brown soils, and the desert soils changed more than 0.10 pH unit in any of their horizons on drying. This statement also applies to four-fifths of the lateritic soils, to three-fourths of the immature profiles, to two-thirds of the imperfectly drained soils of lateritic regions, to more than one-half of the podsolic soils from the Eastern and Midwestern States, and to approximately one-half of the podsols and degraded chernozems.

The horizon samples from the reddish-brown pedocals, from the lateritic group, from the imperfectly drained profiles of lateritic regions, and from the immature profiles which had changed appreciably on air drying were best restored to the pH value of the original moist samples by allowing them to stand in distilled water from 18 to 24 hours. The horizon samples from the podsol profiles, from degraded chernozems, and from podsolic profiles of the Pacific coast which had changed more than 0.10 pH unit on drying were best restored to within that limit of variation from the fresh moist samples by being moistened from four days to a week before making the determinations. The horizon samples from the podsolic profiles of the Eastern and Midwestern States, which had changed appreciably on becoming air-dry, were intermediate in their responses to the two restorative treatments. The humus horizons which most resembled the raw humus layers of the podsols required the same treatment,

but the others were best restored by having the distilled water stand on them from 18 to 24 hours before making the determinations.

The most important factor affecting the changes in reaction from air drying appears to be the amount of acid organic matter present in the sample.

The general conclusion is that hydrogen-ion determinations should be made on air-dried soils rather than on samples fresh from the field.

LITERATURE CITED

(1) AARNIO, B.
1928. DIE VERÄNDERUNG DES AZIDITÄTSGRADES DURCH TROCKNEN DER BODENPROBEN. Bul. Agrogeol. Inst. Finland 26, 11 p., illus.

(2) ACHROMEIKO, A.
1928. DER EINFLUSS DES PULVERISIERENS UND TROCKNENS DES BODENS AUF DESSEN FRUCHTBARKEIT. Ztschr. Pflanzenernähr. u. Düngung (A) 11: [65]–89, illus.

(3) ANDERSON, M. S., and BYERS, H. G.
1931. CHARACTER OF THE COLLOIDAL MATERIALS IN THE PROFILES OF CERTAIN MAJOR SOIL GROUPS. U. S. Dept. Agr. Tech. Bul. 228, 24 p.

(4) ANDREWS, J. C.
1924. EXPERIMENTAL STUDIES ON PALLADIUM ELECTRODES. Jour. Biol. Chem. 59:479–494.

(5) BAVER, L. D.
1926. THE USE OF THE QUINHYDRONE ELECTRODE FOR MEASURING THE HYDROGEN-ION CONCENTRATION OF SOILS. Soil Sci. 21:167–179, illus.

(6) ———
1927. FACTORS AFFECTING THE HYDROGEN-ION CONCENTRATION OF SOILS. Soil Sci. 23:399–414, illus.

(7) BIILMANN, E., and TOVBORG-JENSEN, S.
1927. ON THE DETERMINATION OF THE REACTION OF SOILS BY MEANS OF THE QUINHYDRONE ELECTRODE. Internatl. Soc. Soil Sci., 2nd Comm. Trans. B:236–274, illus.

(8) BLACKADDER, T.
1925. RIPENING OF HYDROGEN ELECTRODES. Jour. Amer. Leather Chemists Assoc. 20:17–19.

(9) BRAY, R. H.
1928. APPARATUS FOR MEASURING THE HYDROGEN-ION CONCENTRATION OF THE SOIL. Indus. and Engin. Chem. 20:421–323, illus.

(10) BURD, J. S., and MARTIN, J. C.
1924. SECULAR AND SEASONAL CHANGES IN THE SOIL SOLUTION. Soil Sci. 18:151–167.

(11) BURGESS, P. S.
1922. THE HYDROGEN-ION CONCENTRATION OF SOILS AS AFFECTED BY DRYING. Sci. (n. s.) 55:647–648.

(12) ———
1924. THE EFFECT ON PRESENT SOIL REACTION OF LONG-CONTINUED APPLICATIONS OF EQUIVALENT AMOUNTS OF HIGH-CALCIUM AND HIGH-MAGNESIUM LIMES. Soil Sci. 18:169–172.

(13) CLARK, W. M.
1928. THE DETERMINATION OF HYDROGEN-IONS; AN ELEMENTARY TREATISE ON ELECTRODE, INDICATOR AND SUPPLEMENTARY METHODS . . . Ed. 3, 717 p., illus. Baltimore.

(14) COLES, H. G., and MORISON, C. G. T.
1930. DEHYDRATION AND SOIL ACIDITY. Soil Sci. 29: 59–70, illus.

(15) ERDMAN, L. W.
1921. THE EFFECT OF GYPSUM ON THE SOIL REACTION. Soil Sci. 12:433–448.

(16) GARDNER, F. D., AND BROWN, B. E.
1911. THE LIME REQUIREMENT OF THE GENERAL FERTILIZER PLATS AS DETERMINED PERIODICALLY. Penn. Agr. Expt. Sta. Rpt. 1910–11 (pt. 2):25–60, illus.

(17) GILLESPIE, L. J.
1916. THE REACTION OF SOIL AND MEASUREMENTS OF HYDROGEN-ION CONCENTRATION. Jour. Wash. Acad. Sci. 6:7–16, illus.
(18) GLINKA, K. [D].
1914. DIE TYPEN DER BODENBILDING, IHRE KLASSIFIKATION UND GEOGRAPHISCHE VERBREITUNG. 365 p., illus. Berlin.
(19) HEALY, D. J., and KARRAKER, P. E.
1922. THE CLARK HYDROGEN-ELECTRODE VESSEL AND SOIL MEASUREMENTS. Soil Sci. 13:323–328.
(20) HEINTZE, S. G., and CROWTHER, E. M.
1929. AN ERROR IN SOIL REACTION DETERMINATIONS BY THE QUINHYDRONE METHOD. Second Comm. Internatl. Soc. Soil Sci. Trans. v. A:102–110.
(21) HILDEBRAND, J. H.
1913. SOME APPLICATIONS OF THE HYDROGEN ELECTRODE IN ANALYSIS, RESEARCH AND TEACHING. Jour. Amer. Chem. Soc. 35:[847]–871, illus.
(22) JOSEPH, A. F., and MARTIN, F. J.
1923. THE HYDROGEN-ION CONCENTRATION OF HEAVY ALKALINE SOILS. Jour Agr. Sci. [England] 13:[321]–332.
(23) KARRAKER, P. E.
1930. THE INACCURACY OF THE QUINHYDRONE ELECTRODE IN MANY KENTUCKY SOILS. Jour. Amer. Soc. Agron. 22:171–180.
(24) KELLEY, A. P.
1923. SOIL ACIDITY, AN ECOLOGICAL FACTOR. Soil Sci. 16: 41–54, illus.
(25) KELLEY, W. P. and MCGEORGE, W.
1913. THE EFFECT OF HEAT ON HAWAIIAN SOILS. Hawaiian Agr. Expt. Sta. Bul. 30, 38 p.
(26) KNICKMANN, E.
1925. UNTERSUCHUNGEN ZUR FRAGE DER BODENAZIDITÄT. Ztschr. Pflanzenernähr. u. Düngung (A) 5: 1–92, illus.
(27) KURZ, H.
1923. HYDROGEN ION CONCENTRATION IN RELATION TO ECOLOGICAL FACTORS. Bot. Gaz. 76: 1–29, illus.
(28) LA MER, V. K., and PARSONS, T. R.
1923. THE APPLICATION OF THE QUINHYDRONE ELECTRODE TO ELECTROMETRIC ACID-BASE TITRATIONS IN THE PRESENCE OF AIR, AND THE FACTORS LIMITING ITS USE IN ALKALINE SOLUTIONS. Jour. Biol. Chem. 57: 613–631, illus.
(29) LIPMAN, J. G., PRINCE, A. L., and BLAIR, A. W.
1921. THE INFLUENCE OF VARYING AMOUNTS OF SULFUR IN THE SOIL, ON CROP YIELDS, HYDROGEN ION CONCENTRATION, LIME REQUIREMENT, AND NITRATE FORMATION. Soil Sci. 12: 197–207, illus.
(30) MARBUT, C. F.
1928. A SCHEME FOR SOIL CLASSIFICATION. First Internatl. Cong. Soil Sci. 1927, Proc. and Papers, Comm. 5, v. 4, p. 1–31, illus.
(31) MATHER, W.
1922. THE EFFECTS OF LIMES CONTAINING MAGNESIUM AND CALCIUM UPON THE CHEMICAL COMPOSITION OF THE SOIL AND UPON PLANT BEHAVIOR. Soil Sci. 13: 337–354.
(32) MCGEORGE, W. T.
1929. THE INFLUENCE OF MANGANIFEROUS SOILS ON THE ACCURACY OF THE QUINHYDRONE ELECTRODE. Soil Sci. 27: 83–88, illus.
(33) PIERRE, W. H.
1925. THE H-ION CONCENTRATION OF SOILS AS AFFECTED BY CARBONIC ACID AND THE SOIL-WATER RATIO, AND THE NATURE OF SOIL ACIDITY AS REVEALED BY THESE STUDIES. Soil Sci. 20: 285–305.
(34) PURI, A. N., and KEEN, B. A.
1925. THE DISPERSION OF SOIL IN WATER UNDER VARIOUS CONDITIONS. Jour. Agr. Sci. [England] 15: [147]–161, illus.
(35) ROBINSON, W. O.
1930. SOME CHEMICAL PHASES OF SUBMERGED SOIL CONDITIONS. Soil Sci. 30: 197–217.
(36) ROST, C. O., and FIEGER, E. A.
1923. EFFECT OF DRYING AND STORAGE UPON THE HYDROGEN ION CONCENTRATION OF SOIL SAMPLES. Soil Sci. 16: 121–126.

(37) SIGMOND, A. A. J. VON (president).
1930. REPORT OF THE COMMITTEE ON SOIL REACTION MEASUREMENTS. . . PART II. CONCLUSIONS AND RECOMMENDATIONS. Soil Research Bd. 2, no. 2, p. [141]–144.
(38) SNYDER, E. F.
1928. METHODS FOR DETERMINING THE HYDROGEN ION CONCENTRATION OF SOILS. U. S. Dept. Agr. Circ. 56, 30 p., illus.
(39) STEENKAMP, J. L.
1928. THE EFFECT OF DEHYDRATION OF SOILS UPON THEIR COLLOID CONSTITUENTS. Soil Sci. 25: 163–182, 239–251, 327–332, illus.
(40) TERÄSVUORI, A.
1930. ÜBER DIE BODENAZIDITÄT MIT BESONDERER BERÜCKSICHTIGUNG DES ELEKTROLYTGEHALTES DER BODEN AUFSCHLÄMMUNGEN. Valtion Maatalouskoetoiminnan Julkaisuja, no. 29, 214 p., illus. Helsinki.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

INVESTIGATIONS ON HARVESTING AND HANDLING FALL AND WINTER PEARS[1]

By W. T. PENTZER, *Assistant Physiologist*, J. R. MAGNESS, *Principal Pomologist*, H. C. DIEHL, *Senior Physiologist*, and M. H. HALLER, *Assistant Pomologist*, *Division of Horticultural Crops and Diseases, Bureau of Plant Industry*

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INTRODUCTION

Estimates based on new plantings coming into bearing indicate a marked annual increase in pear production for at least the next five years. The extension of both foreign and domestic markets is an economic necessity in disposing of the increased pear crop of the future (*11*).[2] The extension of markets must be predicated upon harvesting and handling methods that assure the marketing of first-class pears, in order to attract and hold new customers in the face of increased competition from other fruits. The dessert quality of the fruit when it is ripe and in the hands of the consumer is dependent to a considerable extent upon its maturity at the time it is picked and upon the temperatures to which it is subjected while in transit, in storage, and in the ripening rooms. These two problems, the determination of picking maturity and the effect of transit and stor-

[1] The writers wish to express their appreciation for the assistance of J. C. Shilletter, L. A. Fletcher, B. D. Ezell, and I. A. Van Valkenburgh. The cooperation of the commercial cold-storage companies that made possible the storage tests at different temperatures is also deeply appreciated. Valuable cooperation was also given by fruit growers who made fruit available for these investigations.

[2] Italic numbers in parentheses refer to Literature Cited, p. 28.

age temperatures upon the ripening and storage life of the pear, have been investigated in pear districts of California, Washington, and New York in an attempt to work out the best picking maturity and handling and storage methods for each commercial variety of fall and winter pears.

The commercial harvesting and handling of pears is complicated by certain characteristics of the fruit and by the location of the industry. Pears left on the tree until ripe usually show breakdown at the core and are of very poor quality; hence it is necessary to pick them when they are still unripe but mature enough to ripen with satisfactory dessert quality. It is also essential that harvesting be so timed as to insure maximum shipping, storage, and marketing quality, since most of the fruit is produced far from the consuming markets. At the present time about 68 per cent of the carload shipments originate in California, Oregon, and Washington, and increase in production is expected to continue in the Pacific coast districts. New York is the most important Eastern State in the production of pears, shipping about 18 per cent of the cars moved to market in the United States (*11*).

DETERMINATION OF PICKING MATURITY

As the pear develops on the tree there is a gradual increase in size and a change of the dark leaf-green color to a light or yellow green, accompanied by specific changes within the flesh and skin. The sugar content of the pear increases markedly, starch decreases, and acidity and astringent properties diminish as the fruit approaches proper picking condition (*6*). The growth in size results, of course, in an increase in weight, which for Bartlett pears, according to Murneek (*9*), may amount to over 20 per cent in nine days during the harvesting season. This fact indicates the added tonnage that may result from delayed pickings. As the fruit matures, the skin of some varieties develops a bloom or wax, and the lenticels in the skin become more or less filled by a corky substance that reduces the rate of moisture loss from the fruit. Early pickings of Bartlett pears have been found to lose 9.7 per cent of their weight in 11 days, while pickings made 15 days later lost but 6.3 per cent in the same length of time (*3*). Because of these changes accompanying maturity, fruit picked very early lacks sweetness and richness of flavor, is sometimes sour and astringent, and often shrivels if exposed to a dry atmosphere.

While these modifications are taking place within the flesh and skin, other developments are noticed as the fruit approaches picking maturity. The seeds may become brown, and the stem may loosen somewhat from the tree. The flesh gradually becomes "springy" and softer, although it may still be quite hard to the pressure of the thumb. By means of a mechanical tester, which measures in pounds the pressure required to force a smoothly rounded plunger into the flesh of the fruit to a definite depth, the softening of the pear can be determined in measurable terms. Such a tester is described and illustrated by Magness and Taylor (*8*). Other means of determining maturity, such as starch or sugar tests, specific-gravity tests, color, and size, have been used; but from one season to another, under varying growing conditions, the firmness of the flesh has been the

1

2

3

4

COLOR CHART FOR USE IN DETERMINING PROPER TIME FOR PICKING FALL AND WINTER PEARS

best single index of maturity. The use of the pressure test, correlated with the ground color of the fruit expressed in numbers, as illustrated by the color chart (pl. 1), is increasing in the Pacific Coast States as a maturity standard for pears.

Picking the fruit from the tree early in the season materially reduces not only the tonnage but also the sugar content and dessert quality. On the other hand, allowing it to remain on the tree very late may favor the development of storage disorders and may necessitate special handling to enable the fruit to be shipped without arriving on the market in a soft condition. In the Santa Clara Valley of California, the Wenatchee Valley of Washington, the Hudson River Valley of New York, and the Grand Junction district of Colorado, picking, storage, and shipping experiments have been made with the principal commercial varieties of fall or storage pears grown in these districts. This work was carried on during the sea-

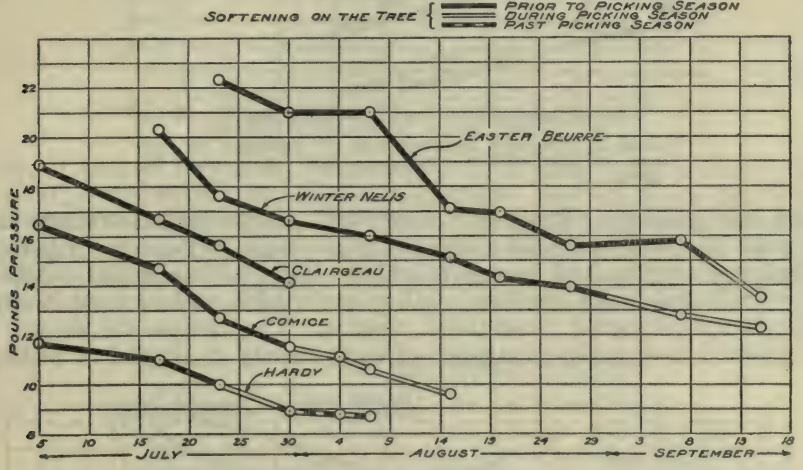

FIGURE 1.—Diagram showing rate of softening on the tree for five varieties of Santa Clara Valley pears in 1926

sons of 1926 and 1927 in California and New York; 1926, 1927, and 1928 in Washington, and in 1929 in Colorado.

EXPERIMENTAL METHODS

The rate at which the different varieties of pears softened on the tree was ascertained by making pressure tests regularly, beginning several weeks before the picking season and continuing beyond the commercial season. In this work, a plunger five-sixteenths of an inch in diameter, which is the size recommended for pears, was used. Care was taken to screw the plunger all the way in so that its depth of penetration should be uniformly five-sixteenths of an inch. Several orchards were visited in each district or in each part of the valley; and the fruit selected for testing was taken from the same trees each time, in order to eliminate variations due to stock or environmental conditions. By using 10 or more pears picked from several trees in each orchard for a single determination, a fairly significant average of the condition of the pears on successive dates was obtained. On each fruit the skin was pared from a small area on three sides and a

test made in each of these places. Curves portraying the softening rate of each variety are given in Figures 1 to 6.

In order to correlate the time of picking with the dessert and storage quality of the pears, several pickings of each variety were made during the season, consisting usually of a preseason, midseason,

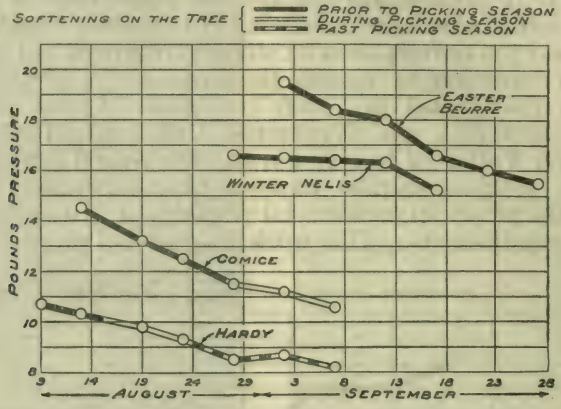

FIGURE 2.—Diagram showing rate of softening on the tree for four varieties of Santa Clara Valley pears in 1927

and late picking. These lots were held at commercial storage and transit temperatures and inspected from time to time for ripening quality, maturity, and storage troubles. The picking period in which the fruit developed the best quality and had a satisfactory storage life was determined from these records. The ranges are shown in Figures 1 to 6, and a discussion of each variety in regard to picking

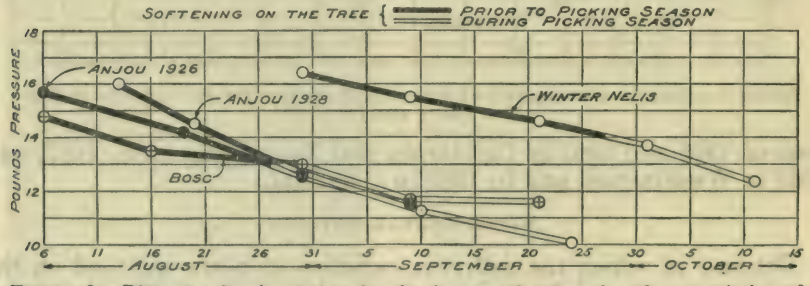

FIGURE 3.—Diagram showing rate of softening on the tree for three varieties of Wenatchee Valley pears in 1926 and one in 1928

season follows. Both of the seasons in New York during which the investigations were conducted were unusually wet and cold, as indicated by the weather records in Table 2; therefore definite conclusions can not be drawn for the picking maturity of pears in this district.

HARVESTING SUGGESTIONS FOR DIFFERENT VARIETIES

HARDY

The Hardy (*Beurre Hardy*) pear is one of the two leading varieties of California fall pears and is the earliest one on the market,

closely following the Bartlett of California. The movement of this variety generally begins about the first week in August. It is not a long-keeping variety, and its quality is more dependent upon careful handling than that of some of the later, firmer pears. Its tend-

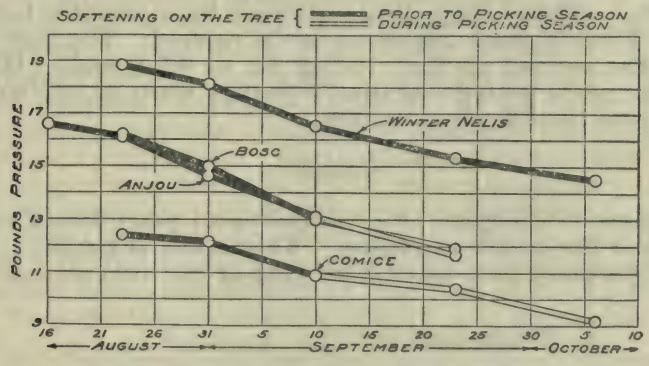

FIGURE 4.—Diagram showing rate of softening on the tree for four varieties of Wenatchee Valley pears in 1927

ency, if picked too early, to wilt and to develop only a mediocre, insipid, often astringent flavor necessitates leaving it on the tree until well matured. Since the Hardy tree will hold its fruit until late in the season, it is not so much the fear of losing some of the crop by dropping, but rather the desire to get a premium for early fruit that is responsible for shipments of immature pears. When

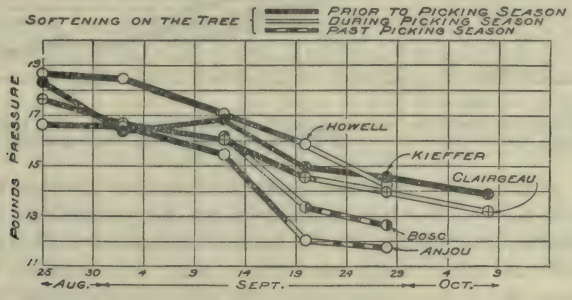

FIGURE 5.—Diagram showing rate of softening on the tree for five varieties of Hudson River Valley pears in 1927

this variety is at its best, its tender, juicy, aromatic flavor is distinctly attractive. If picked too late, its storage life is materially reduced.

As this pear approaches picking maturity its skin loses its dark-green color and begins to show a light-green hue, approximating color standard No. 2 in the color chart. (Pl. 1.) The flesh undergoes a gradual softening, usually at a slightly lower rate during the picking season than just prior to it. In 1926, the pears softened on the tree from July 5 to August 7 from 11.7 to 8.7 pounds, as determined by pressure tests, or approximately 0.1 pound a day. In 1927 the softening was at the rate of about 0.09 pound a day during the ripening period on the tree. Good dessert and storage quality

was obtained in both seasons when the pears were picked at a pressure test between 10 and 9 pounds. The pears of earlier pickings shriveled considerably and lacked sweetness and richness of flavor, and those of later pickings softened rapidly at storage and transit temperatures. On the basis of these tests, Hardy pears should not be picked at a greener stage than indicated by a pressure test of 10 pounds if fairly good quality is to be secured. The best dessert quality was secured in fruit testing 8.5 to 9.5 pounds. However, the larger pears testing less than 9 pounds when picked tended to develop core breakdown in storage.

CLAIRGEAU

Shipments of Clairgeau (*Beurre Clairgeau*) pears from California begin about the middle of August. The variety is classed as one of minor importance, only about 7 per cent of the total acreage in fall

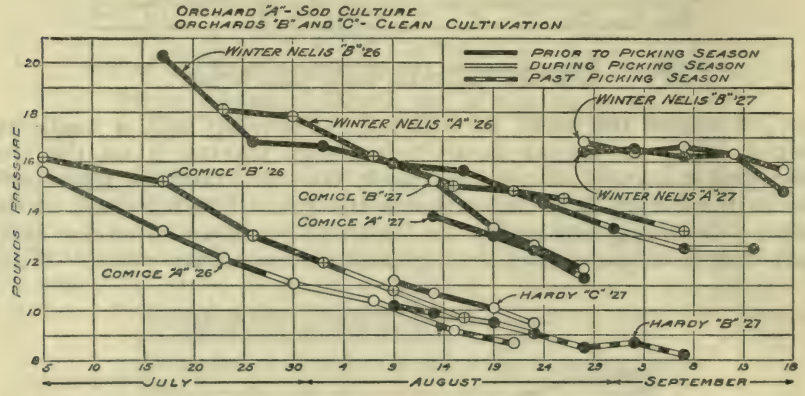

FIGURE 6.—Diagram showing comparative rates of softening on the tree for Santa Clara Valley pears grown in different orchards in 1926 and 1927

and winter pears being devoted to this variety. In the 1926 season the pears softened on the tree from 18.9 to 14.1 pounds as determined by pressure tests, from July 5 to 30, or an average of 0.19 pound a day. In the Hudson River Valley, where this pear is second to the Kieffer in importance, there was practically no softening on the tree in 1926 from September 7 to 30. However, in 1927, during the 44 days from August 25 to October 8, a softening of over 4.6 pounds was noticed, or about 0.1 pound a day. In the Wenatchee district the rate of softening was 0.08 pound a day in 1927 and 0.07 in 1928. The softening rate was fairly uniform throughout the season, which was terminated by the pears dropping from the tree.

The storage life of Clairgeau pears is limited by the development of scald. Since this storage disorder is decreased by late picking, the general recommendation is to allow this variety to remain on the tree as long as possible. The dropping of fruit from the tree usually determines the harvest date of this pear. By this practice the dessert quality is enhanced and the length of the storage life extended. In California the best time to pick was when the pears showed pressure tests of less than 13 pounds; in New York the range

was less than 14.5 pounds; while in the Wenatchee district it was generally less than 14 pounds.

ANJOU

The Anjou (*Beurre d'Anjou*) pear is not a leading commercial variety in California, but holds second place among the late pears in Washington, and is a very important variety in Oregon. It is grown to some extent in the Hudson River Valley of New York. Anjou pears are generally harvested in early September in the Pacific Northwest and somewhat earlier in California. As the Anjou pear matures on the tree its skin undergoes a noticeable change that is a valuable index of maturity. The skin takes on a characteristic waxy finish, losing to some extent its pebble-grained appearance as well as its dull, lusterless look. Since Anjou is very susceptible to wilting if picked immaturely, this skin change, with its accompanying corking over of the lenticels, is important as an insurance against moisture loss and subsequent shriveling. The fruit of the Anjou variety loosens from the tree somewhat markedly as it approaches picking maturity, and some loss from dropping frequently occurs. The increase in size of the fruit remaining on the tree, however, will compensate in tonnage for considerable loss from dropping.

In the Wenatchee Valley this variety showed a gradual softening on the tree, amounting to about a 0.12-pound pressure a day in 1926, 0.13 a day in 1927, and 0.14 a day in 1928. In the Hudson River Valley during the 1927 season there was a softening on the tree from 16.7 pounds on August 25 to 11.8 pounds on September 28, or a daily softening of about 0.15 pound. The rate of softening was most rapid just preceding the picking season. Figures 3, 4, and 5 show the softening rate of this variety in the Wenatchee and Hudson River Valleys. In Washington the best quality has generally been obtained with this variety when picked at a pressure test of 13 to 10 pounds, with a ground color from 2 to 2½, as indicated by shades between 2 and 3 in Plate 1. In New York the best range for picking is estimated to be between 13 and 12 pounds. In Oregon the pressure test range recommended by Hartman (*4*) is 14 to 10 pounds. In the Grand Junction district of Colorado during the 1929 season there was a softening of Anjou pears from 14.6 pounds on August 24 to 12.2 pounds on September 19, or a daily softening of 0.09 pound. Storage tests for the one season would indicate a picking range for this district of 14 pounds or less.

COMICE

Comice (*Doyenne du Comice*) first reaches market from the Pacific coast in the early part of September, the marketing season extending to the Christmas holidays. According to Shear (*11*), this variety ranks fourth in importance among fall and winter pears, Winter Nelis, Anjou, and Bosc preceding it, in the order of their importance, in the sales of Pacific coast pears in the New York auction. During the 1926 season in California this variety softened on the tree from 16.5 to 9.6 pounds from July 5 to August 15, or about 0.17 pound a day. The softening rate was most rapid just preceding the picking season. In 1927 these pears softened about 0.16 pound a

day; and the rate was fairly uniform throughout the season, as indicated in Figure 2. In the Washington district the rate of softening on the tree was somewhat less, amounting to 0.07 pound a day in 1927 and 0.05 pound a day in 1928.

Although Comice pears are not so subject to wilting as Hardy, they require very careful handling to prevent bruising and subsequent darkening of the skin. The use of paper between layers of pears of this variety in the picking boxes is not an uncommon practice to prevent stem punctures and bruising. When picked too early and ripened, this variety is inclined to be somewhat astringent and the skin tough. The best dessert and storage quality was obtained in California Comice by picking when the pressure test was 11.5 to 9 pounds. At the lower figure the fruit became soft sooner than earlier pickings, but the flavor was slightly sweeter. Washington Comice pears were of the best quality when picked at a pressure test of 10 pounds. Good results were also secured when these pears were picked at a pressure test of 11 to 9 pounds. The ground color at this stage of maturity is generally from 2 to 2½.

BOSC

Bosc (*Beurre Bosc*) pears are on the market about the same time as Comice. This variety is grown in all of the Pacific Coast States and also in New York. The Rogue River Valley in southern Oregon is the largest producer of this variety. As work with Bosc in California has been somewhat limited, definite recommendations are not available, but present results indicate that it should be picked at a lower range than in the Medford district of Oregon, where the recommended pressure-test range is from 16 to 14 pounds (*5*). In 1926 the California Bosc softened on the tree at a rate of about 0.08 pound a day. During the same season in Washington the softening rate was 0.07 pound a day, and 0.14 pound a day in 1927. Best quality was obtained with this variety in the Wenatchee Valley when the fruit was picked between 13 and 11 pounds, with the ground color 2½ to 3. The firmness of the best pears was usually about 12 pounds when picked.

The color chart can not readily be used with Bosc pears because of the peculiarly characteristic color of this variety. There is, however, a distinct development of a golden-yellow color as proper maturity approaches.

A characteristic smooth, glossy finish also appears on the Bosc pear as an index of maturity, and there is some loosening of the fruit on the spur.

The late picking of Bosc may predispose the fruit to core breakdown or to breakdown beginning in the slender neck of the fruit. If picked very late, Bosc, when ripened, may have a surface discoloration resembling scald, which occurs particularly on the neck of the pear.

The picking of Bosc in an immature condition generally results in the shriveling of the neck of the fruit while it is in transit or in storage.

In New York during the 1927 season these pears softened a little over 5 pounds from August 25 to September 28, or about 0.15 pound a day. During the picking season the pressure test ranged from

about 15.5 to 13.5 pounds, with only fair quality developing in any of the pickings in either season.

HOWELL

The Howell variety is grown to some extent in the Hudson River Valley and is one of the less important varieties in the Pacific Coast States. During the 1927 season in New York the pears softened on the tree from 18.7 to 14.3 pounds from August 25 to September 28, or about 0.13 pound a day. The softening was most rapid during the latter part of the season. It is probable that pressure tests of 16 to 14 pounds at picking would give satisfactory storage and dessert quality.

KIEFFER

In the Hudson River Valley and in most of the other eastern pear districts the Kieffer leads all other winter pears in commercial importance. During the 1927 season the pears softened from 18.4 to 14 pounds from August 25 to October 8, or at the rate of about 0.1 pound a day. The rate of softening was fairly uniform, as Figure 5 indicates.

In all the lots picked there was much shriveling, suggesting that as a general practice this variety is picked too early. It is likely that fruit picked at a firmness of about 13.5 pounds would be better in quality than earlier pickings.

FLEMISH BEAUTY

The Flemish Beauty variety is of some importance in the Wenatchee district and finds considerable favor in the export trade.

When the fruit is harvested immaturely it loses its characteristic flavor and becomes insipid and watery after it is ripened; it also wilts very readily and has a dull appearance. When properly picked, however, it has a very pleasing flavor, fine-textured flesh, and an attractive appearance in the ripened condition.

In the 1927 season in Washington the pears softened at the rate of about 0.13 pound a day; in 1928 the rate was about 0.17 pound a day. Flemish Beauty pears picked at a pressure test of 13 to 10 pounds, with a ground color from 2 to 2½, ripened satisfactorily and kept well in storage.

When the pear is mature its skin assumes a characteristic smooth finish and may often exhibit a blushed cheek. It drops from the tree quite easily when ready to harvest.

LAWRENCE

Lawrence pears are grown to some extent in the Grand Junction district of Colorado. They are of good quality and keep well in storage. During the season of 1929 this variety at Grand Junction softened from 16.9 pounds on September 13 to 13.2 pounds on October 3, or an average softening of 0.18 pound a day. Storage tests for the one season indicated that the dessert quality was not appreciably improved by allowing the fruit to remain on the tree after reaching a pressure test of 16.9 pounds. The storage quality

was improved, however; so that for best storage and dessert quality a pressure test range of 15.5 to 13.0 pounds at picking time would seem to be desirable.

WINTER NELIS

Winter Nelis is at the present time the leading late pear of the Pacific coast, making up an important portion of the crop from all three States. In California it is generally harvested in early September but is usually held in storage until after Christmas. Harvest in Oregon and Washington is in late September or early October. It is the principal dessert pear on the markets from midwinter until late in the spring. Because of its naturally long life, this pear is not so difficult to handle as some of the softer, more perishable varieties such as the Comice and Hardy. However, many boxes of Winter Nelis reach the consumer with most of the elements of its characteristic spicy, sweet flavor lacking because of its being picked too early. When harvested in an immature condition the pear is somewhat astringent upon ripening; it lacks the attractive yellow ground color showing through the russet and is often shriveled about the stem. Although such pears may be acceptable to those who have never eaten a Winter Nelis in prime condition, they do not stimulate the demand for this excellent winter pear.

During the 1926 season in California the pears softened 8 pounds from July 17 to September 15, or about 0.13 pound per day. (Fig. 1.) In 1927 the rate of softening was less, amounting to 0.07 pound per day. (Fig. 2.) Winter Nelis pears developed the best dessert quality and had a satisfactory storage life when picked at a pressure test of 13.5 to 12 pounds. When the pears were left on the tree until testing 12.5 to 12 pounds, the quality was very good, the pears being sweeter and richer in flavor than earlier pickings, and the storage season was not materially reduced. Fruit testing less than 12 pounds when picked has a tendency to core breakdown in storage, while that picked at a pressure test of over 14 pounds was often astringent in flavor.

In the Wenatchee Valley the rate of softening on the tree was 0.1 pound a day for each of the seasons of 1926, 1927, and 1928. Winter Nelis pears from this district were of the best quality when picked at a pressure test ranging from 14 to 10 pounds, with a ground color of 2 to 2½. The very best pears were usually those picked at about 11 pounds by pressure test. In Oregon, a range of 14 to 11 pounds is likewise recommended (*4*). Since this variety usually clings to the tree well and the market season for the pear is primarily winter and spring, it is best to leave the fruit until well matured.

EASTER BEURRE

Easter Beurre (*Easter*) pears are grown principally in California, but some plantings of this variety are being made in the Pacific Northwest. It is one of the longest-keeping pears, most of the fruit being marketed in the early spring months. Easter Beurre pears offer few hazards in handling, being hard, with a rather rough skin, and slow to ripen. However, in the present tests, earlier pickings of this variety did not ripen with an attractive yellow color when removed from storage and were inclined to be dry and insipid in flavor,

showing some wilting, especially on the smaller specimens. Later pickings were much more attractive and better flavored and held better in storage. In 1926 this variety softened on the tree in California at the rate of 0.16 pound a day just prior to, and during the harvest season, and exhibited the same rate in 1927; in Washington the rate was slightly less for these two years. Easter Beurre pears picked at pressure tests of less than 15 pounds gave the best results in both dessert and storage quality.

SUMMARY OF PICKING RECOMMENDATIONS

The pressure-test range and ground color indicating the picking condition for best dessert and storage quality for each variety studied in California, Washington, and Colorado where typical seasons were encountered are summarized in Table 1.

TABLE 1.—*Pressure-test ranges and ground color indicating best dessert and storage quality of pear varieties from California, Washington, and Colorado*

Variety	Pressure-test range	Ground color [1]	Locality
	Pounds	*Number*	
Hardy	10 to 9	2	Santa Clara Valley, Calif.
Clairgeau	Less than 13		Do.
Do	Less than 14		Wenatchee Valley, Wash.
Anjou	13 to 10	2 –2½	Do.
Do	Less than 14		Grand Junction, Colo.
Comice	11.5 to 9		Santa Clara Valley, Calif.
Do	11 to 9	2 –2½	Wenatchee Valley, Wash.
Bosc	About 14 or less		Santa Clara Valley, Calif.
Do	13 to 11	2½–3	Wenatchee Valley, Wash.
Flemish Beauty	13 to 10	2 –2½	Do.
Lawrence	15.5 to 13		Grand Junction, Colo.
Winter Nelis	13.5 to 12.0		Santa Clara Valley, Calif.
Do	14 to 10	2 –2½	Wenatchee Valley, Wash.
Easter Beurre	Less than 15		Santa Clara Valley, Calif.
Do	do	2	Wenatchee Valley, Wash.

[1] An explanation of the color scale used is given in connection with the color chart illustrated in Plate 1.

EFFECTS OF TOO EARLY PICKING

A comparison of the best picking maturity for the foregoing varieties with the maturity at which many growers have been picking their pears strongly suggests that the practice of picking pears too early in the season has been followed by many orchardists in the past. In the last few years, however, there has been a commendable tendency toward paying more attention to the picking maturity of shipping pears, which has resulted in an improvement in the quality of the product. Certain varieties, particularly Winter Nelis, Anjou, Clairgeau, and in some cases, Hardy, are still generally picked too early for best dessert and storage quality. Overholser and Latimer (*10*), working with California varieties, call attention to this practice by some growers and emphasize the superior dessert and storage quality resulting from pickings of Santa Clara Valley Bosc, Comice, and Hardy made two weeks later than the commercial harvest period.

UNRELIABILITY OF PICKING DATES AND SIZE AS INDEXES OF MATURITY

The unreliability of dates as a picking guide is clearly brought out by the comparison of the seasons shown in Figure 6. In 1926

Comice pears had reached picking maturity by July 27 in orchard A, whereas in 1927 the same maturity was not reached until August 27, a difference of 31 days. In orchard B the difference was 26 days between the two years in this variety. While these differences are very marked because 1926 was an unusually early season, they exist to some extent from year to year, complicating the setting of picking dates.

It is recommended that the grower set a tentative harvest date for each variety, considering the earliness of the season in respect to past seasons and, before this date, give several weeks of attention to the maturity of the fruit itself. By using the pressure tester and color charts, the ripening of the fruit can be followed with the reasonable certainty of knowing when the pears should be removed from the tree.

VARIATION IN FRUIT MATURITY IN DIFFERENT ORCHARDS

The necessity of making the application of maturity data to one's own orchard rather than following the picking period of a neighboring orchardist, no matter how carefully determined by him, is shown by a comparison of picking data of orchards. (Fig. 6.) The three orchards A, B, and C were within a radius of 4 or 5 miles, but A was in sod, and B and C were clean cultivated. The Comice trees in A were older than those in B, while the Winter Nelis trees were about the same age. The Hardy trees in orchards B and C were approximately the same age. A rather marked difference is noticed between the rate of softening of the Comice in orchards A and B during the 1926 season; the difference was evident in 1927 but not so marked. In 1926 this variety was ready to pick about a week earlier in orchard A than in orchard B; in 1927 the difference was about three days, likewise in favor of orchard A. Although the rate of ripening of the Winter Nelis variety followed the same trend in both seasons, the fruit in orchard A reached picking maturity first in 1926 and 1927. As Figure 6 indicates, the Hardy pears were ready to pick about a week earlier in orchard B than in orchard C, both of the orchards being clean cultivated and about the same age. No attempt is made to explain the earliness of the harvest in one orchard with respect to another; but the character of the soil, age of the trees, cultural conditions, and kind of stock undoubtedly affect the maturity of the fruit. Hartman (*5*) found that in regions of lighter soil Bosc pears were ready to harvest earlier than in parts of the Rogue River Valley, Oreg., where heavier soils predominate. This fact has also been observed for a number of the varieties of pears grown in the Wenatchee district. Murneek (*9*) likewise noticed a difference in the time of ripening between orchards of Bartlett pears and emphasized the value of the pressure tester in showing these environmental differences.

CARE IN USE OF PRESSURE TESTER

In using the pressure tester certain precautions should be followed to eliminate errors. One of the most common mistakes made is that

of not selecting adequate or representative samples of fruit for testing. Not less than 10 pears should be tested from the orchard at one time, and these should be selected with regard to size and color, in accordance with picking practices. If the practice is to make several pickings, removing the largest and most mature-looking fruit at each picking, then this is the kind of fruit that should be selected for the pressure test. If all the fruit is to be removed at one picking, an assortment of sizes should be taken and consideration given to the amount of fairly ripe and somewhat green fruit on the tree. The flesh on two or three sides of each pear should be tested to get an average of its texture. By selecting fruit from several trees in different parts of the orchard, obviously a better average of the condition of the crop is obtained than if only one part of the orchard is tested. If decided differences in soil conditions are found in an orchard, it may be advisable to test the fruit separately from these different locations.

The actual manipulation of the pressure tester requires reasonable care and attention. The tip of the plunger should be screwed all the way in, as mentioned before, so that the depth of its penetration will be five-sixteenths of an inch, the same dimension as its diameter. If the tip of the plunger becomes rough or misshapen from careless handling, it should be discarded and a new one used. After removing a small area of skin, about one-half of an inch in diameter, the fruit is placed against the hand or wall or any convenient surface and the end of the plunger directed squarely against the cut surface. The opposite end of the apparatus rests against the hand, and the pressure is applied until the plunger penetrates to a sufficient depth (five-sixteenths of an inch) to push the collar against the metal disk, which completes the circuit, lighting the flash light. The number of pounds indicated on the scale by the sharp line between the black tip and the metal surface of the sleeve, called the "indicator line," is read. Some have made the mistake of using the end of the black tip as the indicator line. In using the new type tester the tip of the plunger is pushed into the pear as far as the groove on the tip and the reading is then taken at the place where the rider rests on the scale. It is important to test the reading of the tester from time to time with an accurate platform scale, pressing down on the scale with the tester until the scale registers a certain number of pounds and checking that figure with the one registered by the instrument. If the machine needs adjustment it should be returned to the manufacturer.

EFFECT OF TRANSIT AND STORAGE TEMPERATURES UPON RIPENING

Physical and chemical changes continue to take place within the pear after it is picked. It has been found that in Bartlett pears, from the time of picking until full ripe, there is a decrease in such substances as starch and pectin materials (*6*). The change in the amount and nature of some of these substances, such as pectose, which give rigidity to cell walls, may account for the softening of the flesh during the ripening period. The acid content of well-matured fruit

remained about constant during storage, and all pickings exhibited an increase in sugars while ripening in storage. Temperature has a direct bearing on most of the changes that occur. Pears held at 30° F. for a period of from six weeks to three months and then ripened at 70° contained more sugar than those held at 40° continuously until ripe, a fact which emphasizes the desirability of using temperatures low enough to nearly suspend physiological activities in the fruit rather than temperatures only sufficiently low to retard ripening somewhat. At 37° the respiration rate of Bartlett pears was found to be about twice that at 30° (*7*), and since the rate of CO_2 output and O_2 intake is an index of the speed at which the ripening process is going on, it follows that the pears were ripening about twice as fast at 37° as at 30°. Gore (*2*) found that for every increase of 18° in temperature, the respiration rate increased 2.23 times in Seckel pears and 2.24 times in Kieffer pears. However, Magness and Ballard (*7*) found that the maturity of the Bartlett pear more markedly affects the respiration rate than does temperature. Pears of the same maturity respired only 1.5 times faster at 60° than at 37° when green; as they ripened the rate increased at both temperatures, but much faster at the higher one. At 60° the respiration rate had reached in 16 days an intensity 8 to 9 times that reached at 37° in 25 days. Nevertheless the temperature at which the fruit was held was the controlling factor, as the higher temperature favored ripening and thus caused an increased respiration rate.

In the commercial storage of fall and winter pears one of two methods is generally followed. Where local storage facilities and conditions are favorable, some growers store their fruit at the shipping point and hold it there until ready to market; other growers and dealers prefer to ship the pears immediately after packing to the terminal markets, where they are held in cold storage. Shipping the fruit from the Pacific coast to the Atlantic coast markets takes about 12 days, during which period the pears are subjected to refrigerator-car temperatures. The temperatures of the top layers of fruit in cars during a 12-day transit period have been found to average about 53° F. in nonprecooled shipments and about 43° to 45° in precooled shipments. Thus, if warm fruit is loaded in the refrigerator car, the top layer will be subjected for 12 days to a temperature averaging about 10° higher than if the fruit had been cooled before shipping. Needless to say, the best precooling practices are those that lower the temperature of the fruit as rapidly as possible. Under ordinary conditions 24 to 48 hours are usually required to reduce the temperature of the pears in the center of the boxes to less than 40° F.; if temperatures much higher than this prevail, the fruit can not be considered precooled.

EXPERIMENTAL METHODS

In order to determine the effect of temperature and time of picking on the commercial storage life of the important varieties of fall and winter pears, investigations were conducted with fruit from California, New York, and Washington, in connection with the work of determining picking maturity. To imitate shipping-point storage, fruit from the early, midseason, and late pickings in California was

stored in rooms held at 30° to 32°, at 36°, and at 70° F. on the day on which it was picked, box lots being stored under each condition. In the Wenatchee Valley, Wash., a storage temperature of 32° was used, and with the New York varieties, storage temperatures of 32°, 40°, and 60° were used. The rate of softening at these temperatures was determined by making pressure tests at regular intervals. Samples of pears were removed from the lower temperatures from time to time and ripened at 70° to ascertain the effect of the storage temperature on ripening quality. The feasible commercial-storage period at shipping point for the different varieties was estimated by considering not only the quality and storage defects upon removal from storage but also the ripening and breakdown which would normally occur in transit and during marketing. A margin of safety has been allowed in arriving at these estimates in order to give reasonable assurance that the fruit will arrive at its destination in a firm condition suitable for marketing.

To imitate shipping and storage at terminal markets, lots from each of the pickings in the Santa Clara Valley were placed in storage at 43° and 53° F. on the day the fruit was picked, and after 12 days at these transit temperatures part of each lot was moved to 31° and held until the storage season ended. Pressure tests were taken at 3-day intervals while the pears were held in temperatures of 43° and 53°, and some of the fruit of most varieties was left at these temperatures until ripe. Observations could thus be made on the prolonged effect of such temperatures on the softening of the pear. From the 31° room, samples of pears were removed at successive dates and ripened at 70°, any difficulty in ripening and any defects in the fruit being noted. The end of the commercial-storage season was determined by taking into consideration the effect of longer holding on dessert quality, storage troubles, and softening, allowing some margin of safety for the disposal of the fruit through the ordinary commercial channels.

DATA FOR DIFFERENT VARIETIES

Although the pressure tester was found to be useful in determining the picking maturity of pears, it was of no particular value in the storage work except for studying the effect of temperature on rate of softening, since in many cases the storage life of the fruit is terminated not by gradual softening, but by storage troubles such as core breakdown, scald, wilting, and decay. The commercial-storage life of some of the pears was limited also by the inferior flavor which they developed when held beyond a certain period of time.

Table 2, compiled from United States Weather Bureau climatological data, gives the weather conditions for the three districts during the seasons in which the work was conducted and indicates that in California an almost normal season was encountered in 1927 and that in Washington the 1928 season was close to normal. However, in the Hudson River Valley of New York, the seasons of 1926 and 1927 were abnormally cold and wet, a fact which may have some bearing on the generally poor storage and dessert quality of the fruit from this section in both of these seasons. Rainfall data for

San Jose and Wenatchee are not given, because the rainfall during the growing season of the fruit is negligible and moisture is supplied by irrigation.

TABLE 2.—*Weather conditions during the latter part of the growing seasons*

SAN JOSE, CALIF.

Period	1926			1927		
	Mean temperature	Departure from normal	Clear days	Mean temperature	Departure from normal	Clear days
	°F.	°F.	Number	°F.	°F.	Number
July	68.8	+2.3	30	67.4	+0.9	26
August	67.0	+ .9	25	65.9	−.2	18
September	62.6	−1.6	25	62.8	−1.4	23
October	63.0	+2.9	18	61.8	+1.7	19
Season			98			86

HUDSON, N. Y.

Period	1926					1927				
	Mean temperature	Departure from normal	Rainfall	Departure from normal	Clear days	Mean temperature	Departure from normal	Rainfall	Departure from normal	Clear days
	°F.	°F.	Inches	Inches	Number	°F.	°F.	Inches	Inches	Number
July	69.6	−2.3	3.10	−0.21	20	70.7	−1.2	8.49	+5.18	9
August	69.4	+.7	5.25	+1.23	10	64.3	−4.7	9.51	+5.49	11
September	60.2	−2.7	2.81	−.78	13	61.0	−1.9	2.60	−.99	21
October	47.2	−4.9	4.93	+1.76	10	52.2	+.1	6.37	+3.20	18
Season			16.09	+2.0	53			26.97	+12.88	59

WENATCHEE, WASH.

Period	1926			1927			1928		
	Mean temperature	Departure from normal	Clear days	Mean temperature	Departure from normal	Clear days	Mean temperature	Departure from normal	Clear days
	°F.	°F.	Number	°F.	°F.	Number	°F.	°F.	Number
July	75.5	+2.3	28	73.0	−0.2	25	76.3	+3.0	23
August	70.2	−1.6	23	71.0	−.8	21	71.0	−.7	24
September	56.9	−5.0	21	59.8	−2.1	10	62.6	+1.1	26
October	51.1	+.6	15	49.6	−.9	11	48.6	−1.9	13
Season			87			67			86

In view of the variation between seasons and pickings within the recommended pressure ranges, the storage periods given in Tables 3 to 5 are of more value in comparing the effect of temperature upon ripening than in setting a maximum storage limit that will hold from year to year.

TABLE 3.—*Maximum storage periods of California pears picked in optimum maturity condition*

Variety	1926		1927	
	Storage period	End of storage period	Storage period	End of storage period
	Days	*Month*	*Days*	*Month*
Hardy	125–141	December	76–100	November to December.
Clairgeau	187–197	March		
Comice	120–131	December	55–60	November.
Bosc	167–176	January	115–124	January.
Winter Nelis	233	May	177	April.
Easter Beurre	251	May to June	195–203	April to May.
SHIPPING-POINT STORAGE 31° F.				
Hardy	64–105	October to November	45–60	October.
Clairgeau	102–150	November to January		
Comice	67	October	40–43	Do.
Bosc	126–167	November to January	60	November.
Winter Nelis	175	March	141	February to March.
Easter Beurre	231	May	136–144	Do.
SHIPPING-POINT STORAGE 36° F.				
Hardy	78–109	November to December	52–117	November to December.
Clairgeau	102–187	November to February		
Comice	120–131	December	58–61	November.
Bosc	167–176	January	60–95	November to December.
Winter Nelis	225	May	201	May.
Easter Beurre	231	do	144–225	April to June.
TERMINAL-MARKET STORAGE 31° F. (PRECOOLED SHIPMENTS)				
Hardy	15–18	August to September	33–42	October to November.
Clairgeau	60–187	October to February		
Comice	40–47	September	30–45	October.
Bosc	107–116	November	63–124	December.
Winter Nelis	175	March to April	141	February to March.
Easter Beurre	191	do	136–144	Do.
TERMINAL-MARKET STORAGE 31° F. (NONPRECOOLED SHIPMENTS)				

TABLE 4.—*Number of days required for ripening California pears at different temperatures when picked at optimum maturity and stored immediately*

Variety	Time required for ripening at indicated temperature (°F.) for the year—					
	1926			1927		
	70°	53°	43°	70°	53°	43°
	Days	*Days*	*Days*	*Days*	*Days*	*Days*
Hardy	9–12	15–18	24–30	9	15–18	30–45
Clairgeau	15	20	50			
Comice	12	15–18	30–36	9–12	15	30
Bosc	11–12	21–23	56–60	12	18	45–60
Winter Nelis				12	15–18	30
Easter Beurre				18	27	

TABLE 5.—*Picking season and principal storage troubles, other than mold, of leading varieties of California fall and winter pears*

Variety	Picking dates		Principal storage troubles
	1926	1927	
Hardy	July 20 to Aug. 5	Aug. 20 to 31	Shrivel, core breakdown, scald.
Clairgeau	Aug. 8 to 18		Scald.
Comice	Aug. 1 to 12	Sept. 6 to 13	Core breakdown.
Bosc	July 23 to Aug. 3	Aug. 25 to Sept. 3	Surface and core breakdown, shrivel.
Winter Nelis	Sept. 15	Sept. 16 to Oct. 7	Core and flesh breakdown.
Easter Beurre	Sept. 19	Oct. 4 to 12	Surface and core breakdown.

These data show the storage behavior of California varieties of pears picked at optimum maturity and held at various temperatures, while Table 6 shows the amount of softening that takes place in each of the varieties during 12 days at temperatures representing precooled and nonprecooled shipments. The data show the rate of softening, at various storage and transit temperatures, of midseason pickings representing each variety, respectively. Later, a discussion of the storage life of each variety is given.

TABLE 6.—*Average amount of softening at temperatures approximately those of top layers in cars of different varieties of pears during a period of 12 days, as shown by pressure tests*

Variety	Softening as shown by pressure test		Variety	Softening as shown by pressure test	
	Nonprecooled (53° F.)	Precooled (43° F.)		Nonprecooled (53° F.)	Precooled (43° F.)
	Pounds	*Pounds*		*Pounds*	*Pounds*
Winter Nelis	6.5	1.4	Bosc	3.5	2.1
Hardy	5.4	1.2	Easter Beurre	2.5	.5
Comice	5.0	.6	Clairgeau	1.1	.9

HARDY

Table 3 gives the effect of two temperatures on the storage life of California Hardy pears at shipping point and at terminal market. The data given are for pickings made during the optimum harvesting period of 10 to 9 pounds, as determined by pressure tests, and do not include preseason or late pickings. This variety in 1926 was held at shipping point at 31° F. until December 8; in 1927 it was held until November 28. Although terminating at approximately the same date, the storage season in 1927 was much the shorter of the two, since the date of harvesting in 1927 was about one month later than that in 1926. At 36° the storage life was reduced three to four weeks, ending on November 18 in 1926, and on October 19 in 1927. The length of storage at 31° following 12 days at 43° closely approximated the commercial life at 31° in both seasons, but the amount of ripening resulting from transit temperatures 10° higher reduced the storage life by three to six weeks. After 12 days at 53°, many lots were nearly ripe and were suitable for only

very short holding, if any, at cold-storage temperatures. The New York auction reports (*11*) show that Hardy pears were off the market by the middle of November, 1926, the peak of sales occurring about September 15. In 1927 (*1*) the peak of sales was reached about a month later, as would be expected from the fact that the harvesting period was about a month later than in 1926.

The most common storage defect of Hardy pears was wilting, especially in the fruit of the earlier pickings. That this variety is more susceptible to moisture loss than either Bosc or Comice is indicated by Overholser and Latimer (*10*), who found that early pickings lost 13.7 per cent moisture on ripening as compared with 12.3 and 11.4 per cent, respectively, for Bosc and Comice. They found that in all cases the earlier pickings lost the most weight. Core breakdown was another limiting factor in the storage life of Hardy pears. This variety, except in the very late pickings, would not ripen at cold-storage temperatures but ripened with excellent quality at temperatures of 53° and 70° F. As mentioned later, Clairgeau and

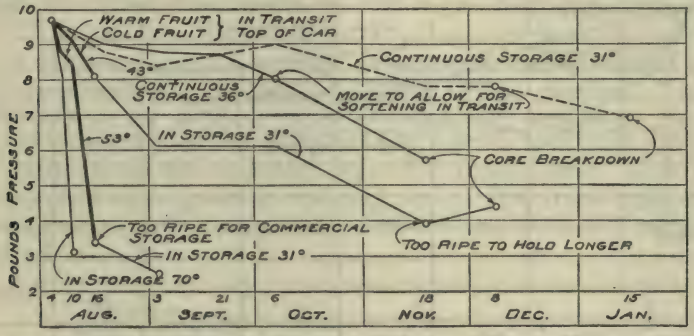

FIGURE 7.—Diagram showing rate of softening in transit and storage for Hardy pears picked late in 1926, in the Santa Clara Valley, Calif.

Bosc were similar to the Hardy in this respect, while Comice, Winter Nelis, and Easter Beurre ripened at 31° and at 36° if held long enough at these low temperatures. The effect of transit and storage temperatures on the rate of softening of Hardy pears is presented in Figure 7.

CLAIRGEAU

All lots of Clairgeau pears from the Santa Clara Valley, Calif., were held in storage at 31° F. in good condition continuously for more than six months, that is, until February 21. Some lots after being held 12 days at 43° and 53° had a similar storage period at 31°. Storage at 36° shortened the season by one and a half to three months, some lots ending their season on November 18. One lot, stored at 31° after being held 12 days at 53°, was in eating-ripe condition by October 6. These dates represent the minimum storage periods, some lots holding up considerably longer at each temperature. Scald was the most important storage trouble. The Clairgeau variety had disappeared from the New York auction by the last of December in 1926, the year in which the investigation was conducted, the peak being reached about the first week in October.

At 32° F. the storage life of the Clairgeau pears from the Hudson River Valley, N. Y., was 80 to 100 days, extending to December and

January; at 40° the storage life was reduced to 30 to 50 days. Clairgeau pears from the Wenatchee Valley, Wash., have been held satisfactorily in storage at 32° for periods of four to six months. This variety of pear from California, New York, and Washington failed to ripen when held continuously at 31°, 36°, and 40°, necessitating its removal from low temperatures to 50° or higher in order to ripen properly. Figure 8 gives the softening rate of California Clairgeaus at 31°, 36°, 53° to 31°, 43° to 31°, and 70°.

ANJOU

The Washington Anjou pears were held in satisfactory commercial condition at 32° F. storage for four to five months, and have been observed in excellent condition even after storage periods up to six months.

When properly picked the Anjou has a very delicious flavor and aroma, with a flesh of melting texture. This variety has frequently

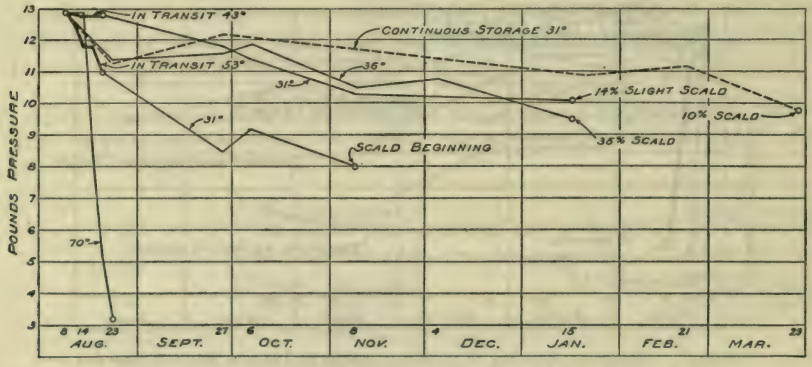

FIGURE 8.—Diagram showing rate of softening in transit and storage for Clairgeau pears picked in midseason, 1926, in the Santa Clara Valley, Calif.

been in a condition too immature to give the highest dessert quality. The highest quality found in any Anjou pears of the experimental lots has invariably been in those picked at a pressure test of from 11 to 10 pounds. If a considerable acreage of this pear is to be harvested, or very late storage is intended, it is generally desirable, however, to start picking when the fruit is somewhat firmer than this pressure, and for these reasons a range of 13 to 10 pounds has been suggested.

The best quality is achieved if the Anjou pears are taken from 32° F. while still green and ripened at temperatures of 60° to 70°.

New York Anjou pears were held in a commercially satisfactory condition at 32° F. for two to three months; at 40°, the limit of their storage life was one month. As heretofore mentioned, all the New York pears studied were of very poor storage and dessert quality, possibly owing to the cold wet growing season prevailing during both years in which the study was made. The softening rate of Washington Anjou pears stored at 32° in 1927 is given in Figure 9. The softening of fruit from four orchards, A to D, is shown. The commercial season for this pear, as indicated by market reports, extended to March in 1926 and to January in 1927, the peak of the sales in

both years falling in December. However, this pear is seen much later on the fruit stands and retail markets.

COMICE

The California Comice was held commercially until November and December at 31° F. Some lots held 12 days at 43°, then at 31° kept almost as long, giving this variety a storage life of 2 to 4 months. At 36° its life was 1½ to 2 months, while in storage at 31° after 12

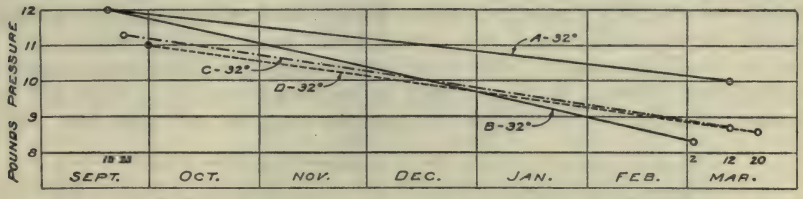

FIGURE 9.—Diagram showing rate of softening in storage for Anjou pears from Wenatchee Valley, Wash., during the 1927 season. Fruit from four orchards, A to D

days at 52°, representing storage at terminal markets after nonprecooled shipment, the pears kept only 1 to 1½ months. The commercial season for Comice pears is practically ended in December, and only lots kept at low temperatures can be held this long. The most common storage disorder was core breakdown. This variety does not need to be given a ripening period at warmer temperatures after cold storage, but may be kept at 31° and 36° until eating ripe, if desired.

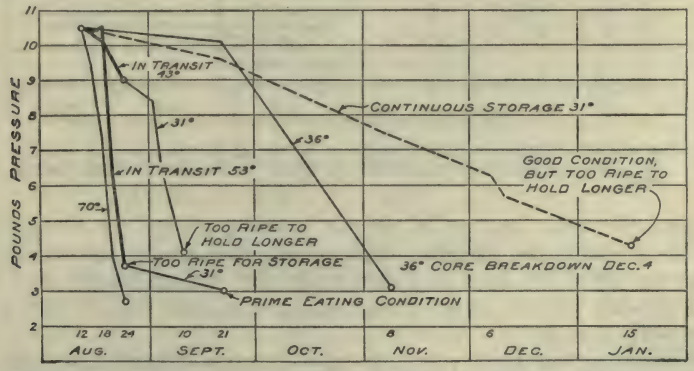

FIGURE 10.—Diagram showing rate of softening in transit and storage of Comice pears picked in midseason, 1926, in the Santa Clara Valley, Calif.

The Washington Comice has been held satisfactorily in storage at 32° F. at Wenatchee for two to three months. It is the common experience in many northwestern fruit districts, however, that the Comice pear requires special care in harvesting and handling. It ripens quickly, is at its best picking maturity when relatively soft, must be handled carefully to avoid injury, and, owing to its rapid ripening habits, must be placed at relatively low temperatures soon after harvest in order to avoid overripeness and core breakdown. The softening rate of this variety is shown in Figure 10.

BOSC

In 1926 California Bosc pears were held satisfactorily in storage until the middle of January, both continuously at 31° F. and at 31° after a 12-day period at 43°, the latter conditions representing terminal-market storage following shipment of precooled fruit. The fruit was held until the middle of November in storage at 31° following 12 days at 53° and about the same length of time in continuous storage at 36°. The storage season was generally shorter at all temperatures in 1927 than in 1926. The principal storage defects observed were surface and core breakdown and wilting, especially at the neck of the pear. The experience with the California Bosc in storage was that it did not ripen at temperatures less than 53° but ripened satisfactorily at that temperature and at 60° and 70°. This

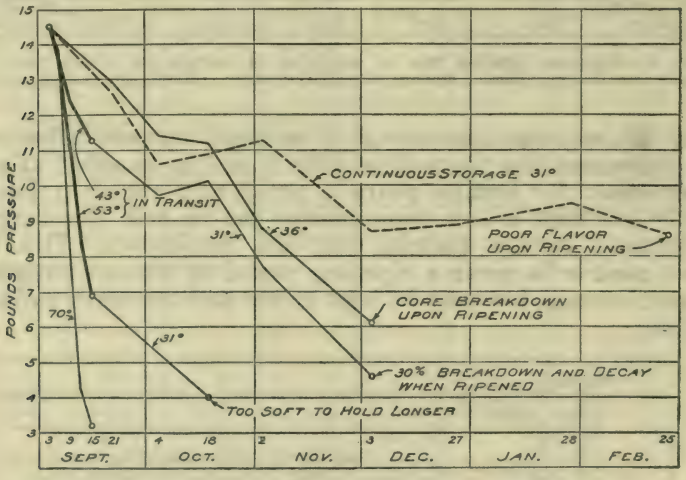

FIGURE 11.—Diagram showing rate of softening in transit and storage for Bosc pears picked in midseason, 1927, in the Santa Clara Valley, Calif.

is in accord with results of recent investigations on Oregon Bosc (*5*). In general, the Oregon Bosc pears had a similar storage life, holding up until the last of January at 32° continuously and at 32° after a 12-day period at 43°, and about a month less at 32° after a 12-day period at 53°.

The Washington Bosc pears from Wenatchee have been generally held in storage satisfactorily at 32° F. for a period of two to three months. Very late picking or very long storage seems to predispose the fruit to internal breakdown or surface discoloration. The Washington pears seem to behave in storage similarly to those from other sections.

In 1926 the storage life of New York Bosc was about 90 days at 32° F. and about 40 days at 40°, enabling it to be held until about the middle of December at 32° and to the last of October at 40°. The New York Bosc behaved similarly to the California, Washington, and Oregon fruit in not ripening at low temperatures. The New York Bosc pears would not ripen at either 32° or 40°, but at 50°

or 60° they developed good quality. Surface breakdown was the most common storage trouble in the New York Bosc. The softening rate of California Bosc pears is given in Figure 11. While most of the sales of this variety on the auction occur in October, some Bosc pears are sold as late as January.

HOWELL

Hudson River Valley Howell pears were held one to two months at 32° F., most lots being ready to move at the end of one month, or

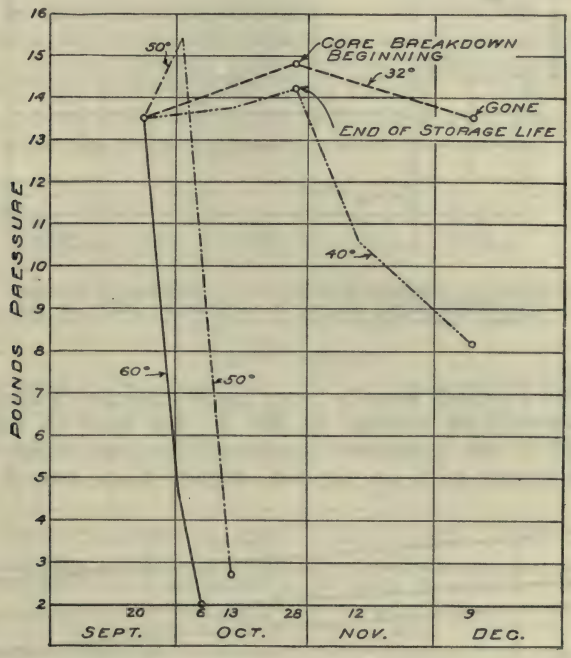

FIGURE 12.—Diagram showing rate of softening in storage for Howell pears picked in midseason, 1927, in the Hudson River Valley, N. Y.

about October 15. At 40° the fruit was held three to six weeks. The storage defects noticed on this variety were core and surface breakdown. Figure 12 shows the effect of temperature on the softening rate of Howell pears.

KIEFFER

The important New York variety, Kieffer, was held in storage one to two months in good condition at 32° F., bringing its season to the last of November; at 40° it held in storage about a month. The pears shriveled considerably and showed some surface breakdown. It is probable that late pickings or fruit grown in more representative seasons with respect to temperature and rainfall would exhibit better

storage quality. Its behavior at various temperatures is shown in Figure 13.

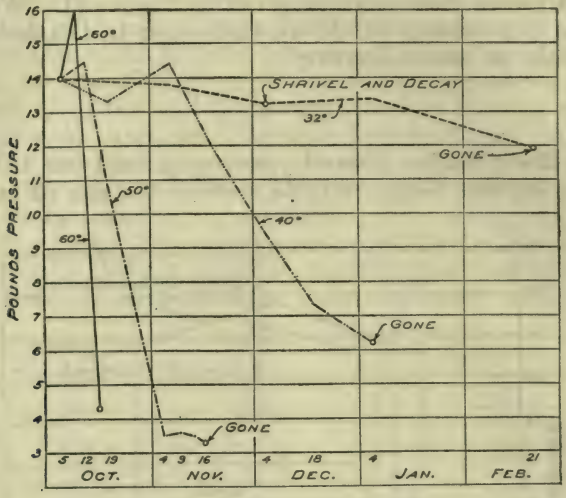

FIGURE 13.—Diagram showing rate of softening in storage for Kieffer pears picked in midseason, 1926, in the Hudson River Valley, N. Y.

FLEMISH BEAUTY

Washington Flemish Beauty from the Wenatchee Valley has been held satisfactorily in storage at 32° F. for four to five months. When picked in an immature condition the fruit wilts readily in storage and ripens with an insipid, watery flesh, but if harvested

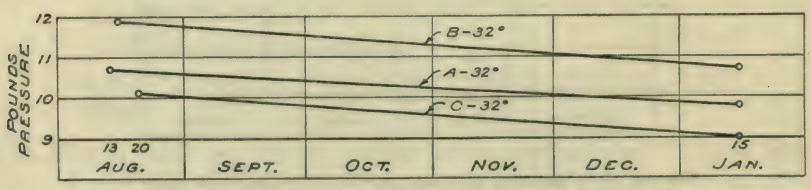

FIGURE 14.—Diagram showing rate of softening in storage for Flemish Beauty pears from the Wenatchee Valley, Wash., during the 1928 season. Fruit from three orchards, A to C

when properly matured it has a delicious, juicy flesh. The softening rates for Washington Flemish Beauty are given in Figure 14.

WINTER NELIS

During both seasons in which investigations were conducted, the Santa Clara Valley Winter Nelis pears were held continuously in storage until April or May at 31° F., and at 31° following 12 days storage at 43°. At 36° storage the pears held in commercial condition until about the first of March. Those held at 31° following 12 days of storage at 53° were in good condition until the last of March in 1926 and until late February in 1927. The results of the investi-

gations indicate that when Winter Nelis pears are kept at a continuous temperature of 31° or shipped after precooling and held at 31° at the terminal market, they can be held seven to eight months. The most common troubles in storage with the California fruit were core and flesh breakdown. Early pickings showed considerable wilting, but in those made in the recommended picking range, this trouble was not serious.

Winter Nelis pears from Washington have been satisfactorily held in storage at 32° F. for periods up to six months. The fruit matures on the trees at a time when atmospheric temperature conditions are favorable; therefore it does not usually require so much haste in harvesting as do most other varieties.

Occasionally the pears are picked in a too immature condition, when they wilt very readily in storage and will not ripen with the spicy, sweet flavor characteristic of the variety. The flesh of Winter Nelis pears picked in an immature condition is very likely to remain astringent when the fruit is ripened.

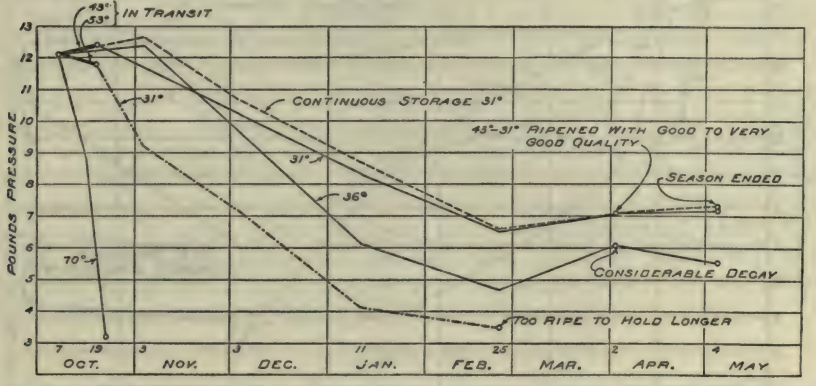

FIGURE 15.—Diagram showing rate of softening in transit and storage for Winter Nelis pears picked late in 1927 in the Santa Clara Valley, Calif.

Figure 15 shows the rate of softening of this variety at transit and storage temperatures.

Evidently some Winter Nelis pears are held to the limit of their commercial storage season, for records of the New York auction in 1926 show sales as late as May, and in 1927 some were disposed of in June at the top price for the year. This variety requires no special attention as to ripening temperature, for it ripens under cold-storage conditions if kept long enough.

EASTER BEURRE

Easter Beurre pears from California held about as long at the various storage temperatures as Winter Nelis. In continuous storage at 31° F. they held until the last of May in 1926 and until the last of April in 1927. In fruit held for 12 days at 43° and then stored at 31° the storage life was about the same; while at 53° to 31° the pears held until February or March. In storage at 36° continuously the fruit in 1926 kept about as long as at 31°, but in 1927 the storage life was a month less at the higher temperature. The effect of low

temperatures in slowing down the ripening processes is shown in Figure 16. Easter Beurre pears are sold chiefly in the late spring and can be found on the market as late as May and June.

Easter Beurre pears from Washington have a long storage life and have been held at 32° F. for periods up to 6 months, and a longer holding period is possible. This is a characteristically long-storage variety and does not seem to develop its best flavor until a period of some months has been passed in cold storage.

EFFECT OF TEMPERATURE ON RATE OF RIPENING

The best temperature for holding all the varieties of pears was 30° to 32° F. While the freezing point of the late varieties of pears has not been determined, the maximum freezing point for Bartlett pears was found to be 28.7° (*13*), indicating that storage tempera-

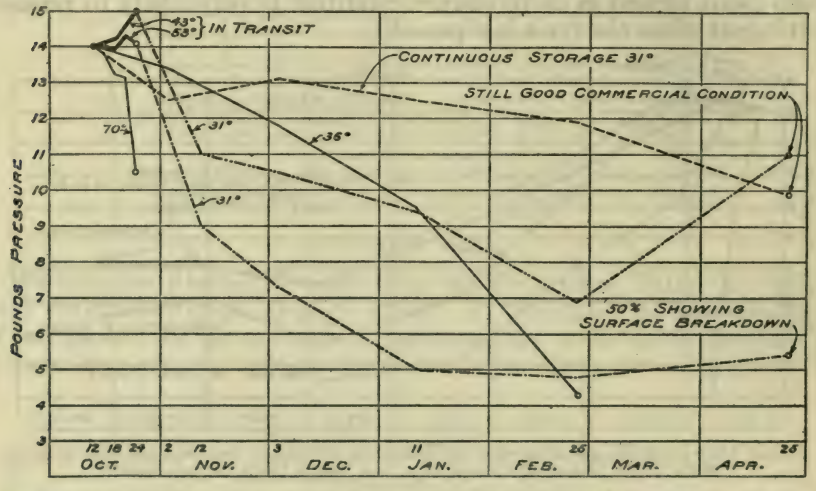

FIGURE 16.—Diagram showing rate of softening in transit and storage for Easter Beurre pears picked late in 1927 in the Santa Clara Valley, Calif.

tures of 30° to 32° may be used without danger of freezing the fruit, provided uniform temperatures are maintained in the storage rooms. As shown by the softening curves for the various temperatures, the ripening rate was markedly affected by temperature. Storage at 36° reduced the life of some of the shorter-lived varieties, such as Comice and Hardy, one-third to one-half as compared with their life at 31°. The effect was not so marked on the slower ripening sorts, such as Winter Nelis and Easter Beurre, but in all cases the storage life was less at 36° than at 31°.

Holding the fruit at fairly high temperatures for a short period immediately after picking has a marked effect upon its softening. Table 6 gives the average amount of softening in each variety as determined by pressure tests, during a 12-day period at 53° and 43°F. These data indicate the amount of ripening taking place in the top layers of fruit in nonprecooled and in precooled shipments, respectively, while in transit to eastern markets.

The difference in the amount of softening is least marked in the Clairgeau and Bosc varieties and most striking in the Comice, Hardy,

and Winter Nelis. From the amount of ripening that takes place during the short period at 53° F., it is not surprising to find the subsequent storage life at 31° only about one-fourth as long in the Hardy and one-half as long in the Comice as the storage life of fruit held at 31° continuously from the time of picking. In comparing the effects of transit at 43° and at 53° on the subsequent storage life at 31°, a study of Table 3 indicates that the lower transit temperature often added two months to the storage life of most varieties. Little difference was noted, however, in the subsequent storage life of Clairgeau pears held at 43° and at 53° during the transit periods. When pears were held 70°, 53°, and 43° from the time of picking to ripening, they reached the ripe stage in about half the time at 53° as at 43° and in about two-thirds the time at 70° as at 53°.

EFFECT OF TEMPERATURE ON DESSERT QUALITY

The temperature at which three of the varieties were ripened was of importance. Hardy, Clairgeau, and Bosc should be held as nearly as possible at 30° to 32° F. until ready for market but should then be removed to temperatures of 60° to 70° to ripen. If these temperatures do not prevail at the place of marketing, the fruit should be placed in a room held at this temperature until it is in firm, eating-ripe condition. Subsequently, it can be exposed to colder temperatures without impairing the quality. While the other varieties of fall and winter pears included in the investigation ripened at cold-storage temperatures, a more attractive yellow color and a more aromatic flavor usually result from ripening at a temperature of about 70°. Much higher temperatures are not desirable and may result in poorly flavored, tough-textured pears, or in losses from decay before softening, as pointed out by Villiers (*12*).

SUMMARY

Allowing pears to remain on the tree until sufficiently mature increases the sugar content and reduces the astringent properties, wilting, and, on susceptible varieties, scald in storage.

Leaving the fruit on the trees too long causes deterioration in quality and may cause serious troubles in storage and transit, such as core breakdown and too rapid softening. Fruit rots are generally more prevalent in pears that are harvested and packed when too mature.

Because of the importance of the effect of the maturity of the pear when picked upon its subsequent dessert and storage quality, the expression of picking maturity in more positive terms has been attempted by using the firmness of the flesh of the pear as the index of maturity and measuring this by means of a pressure tester.

The softening on the trees of the important varieties of fall and winter pears in the Santa Clara Valley, Calif., Wenatchee Valley, Wash., Grand Junction district of Colorado, and Hudson River Valley, N. Y., was determined during the latter part of several growing seasons. The best time to pick the fruit was ascertained by picking at intervals and holding it in storage until ripe. The picking recommendations for each of the varieties studied in California, Washington, and Colorado, where typical seasons were encountered, have been summarized in Table 1 (p. 11).

Chemical and physical changes continue to take place within the pears after they are removed from the trees, the temperature at which the fruit is held markedly affecting the rate of these changes.

For the longest storage life, pears should be held from the time of picking at a temperature of 30° to 31° F. Storage at 36° reduced the storage life one-third to one-half in the shorter lived varieties, such as Hardy and Comice, as compared with their storage life at 31°.

The lowered transit temperatures of precooled shipments generally added one to two months to the subsequent storage life at 31° F. as compared with that of nonprecooled shipments.

For the best dessert quality, the pears should be removed from cold-storage temperatures and ripened at 60° to 70° F. While some varieties will ripen with fairly good quality at low temperatures, Hardy, Bosc, and Clairgeau will not; they require special treatment in this respect.

When handled properly Easter Beurre and Winter Nelis pears can be held in storage at 32° F. for 7 or 8 months. Bosc pears at this temperature can be held 2 to 3 months, and Clairgeau can be held 4 to 6 months. Comice and Hardy can usually be held 2 to 4 months at 32° F. The storage life of Anjou pears at this temperature is usually from 4 to 5 months, although properly handled lots can be held up to 6 or 7 months.

LITERATURE CITED

(1) Brown, C. L.
1928. fall and winter pears. Calif. Cultivator 61: 461, 469.

(2) Gore, H. C.
1911. studies on fruit respiration. I. the effect of temperature on the respiration of fruits. II. the effect of picking on the rate of evolution of carbon dioxide by peaches. III. the rate of accumulation of heat in the respiration of fruit under adiabatic conditions. U. S. Dept. Agr., Bur. Chem. Bul. 142, 40 p., illus.

(3) Hartman, H.
1924. studies relating to the harvesting and storage of apples and pears. Oreg. Agr. Expt. Sta. Bul. 206, 32 p., illus.

(4) ———
1928. pressure test for pear maturity. Better Fruit 23 (4): 14, 19–20.

(5) Magness, J. R., Reimer, F. C., and Haller, M. H.
1927. investigations on the harvesting and handling of bosc pears from the rogue river valley. Oreg. Agr. Expt. Sta. Bul. 228, 30 p., illus.

(6) Magness, J. R.
1920. investigations in the ripening and storage of bartlett pears. Jour. Agr. Research 19: 473–500, illus.

(7) ——— and Ballard, W. S.
1926. the respiration of bartlett pears. Jour. Agr. Research 32: 801–832, illus.

(8) ——— and Taylor, G. F.
1925. an improved type of pressure tester for the determination of fruit maturity. U. S. Dept. Agr. Circ. 350, 8 p., illus.

(9) Murneek, A. E.
1921. a new test for maturity of the pear. pear harvesting and storage investigations. (third report.) Oreg. Agr. Expt. Sta. Bul. 186, 28 p., illus.

(10) Overholser, E. L., and Latimer, L. P.
1924. the cold storage of pears. Calif. Agr. Expt. Sta. Bul. 377, 56 p., illus.

(11) Shear, S. W.
1928. economic aspects of the pear industry. Calif. Agr. Expt. Sta. Bul. 452, 107 p., illus.

(12) VILLIERS, F. J. DE
1925. THE RETARDATION OF THE RIPENING OF PEARS AT HIGH TEMPERATURES. So. African Jour. Sci. 22: 170–190, illus.
(13) WRIGHT, R. C., and TAYLOR, G. F.
1923. THE FREEZING TEMPERATURES OF SOME FRUITS, VEGETABLES, AND CUT FLOWERS. U. S. Dept. Agr. Bul. 1133, 8 p.

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TECHNICAL BULLETIN No. 289 MARCH, 1932

LAND UTILIZATION IN LAUREL COUNTY, KY.

BY

C. F. CLAYTON

Senior Agricultural Economist, Division of Land Economics
Bureau of Agricultural Economics

AND

W. D. NICHOLLS

Head, Department of Farm Economics
Agricultural Experiment Station
University of Kentucky

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.
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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

LAND UTILIZATION IN LAUREL COUNTY, KY.

By C. F. CLAYTON, *Senior Agricultural Economist, Division of Land Economics, Bureau of Agricultural Economics, and* W. D. NICHOLLS, *Head, Department of Farm Economics, Agricultural Experiment Station, University of Kentucky*[1]

In Cooperation with Kentucky Agricultural Experiment Station

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INTRODUCTION

Laurel County is included in a group of 34 counties comprising the Kentucky portion of the Cumberland Plateau. The approximate western border of this region is marked by a line extending southwestward from Portsmouth on the Ohio River to the southwest corner of Wayne County. The rugged or rough topography characteristic of this region has given to it the name of the "Kentucky Mountains." It covers 10,450 square miles, or 26 per cent of the area of the State.

[1] The following divisions of the Bureau of Agricultural Economics participated in the study: Land economics, farm management and costs, and farm population and rural life. Tabulations and summaries of the data relating to individual fields and to farm wood lots were made under the direction of C. F. Clayton, Bureau of Agricultural Economics, who is also responsible for the organization of the material appear-

(Continued on p. 2)

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It seems appropriate to preface the presentation of the data of this initial study of land utilization in the Kentucky Mountains with a brief summary of important conditions which have affected the economic and social development of the mountain region. A general description will serve to indicate the portion of the area in which basic conditions are essentially like those in Laurel County, and for which the results of the present study may be regarded as generally significant. These conditions are the foundation of problems that now confront many mountain communities.

PHYSICAL FEATURES

Physiographically the mountain region is a maturely stream-dissected plateau. With the exception of Pine Mountain and Cumberland Mountain—the only true mountains in the region—the ridges are the result of erosional processes. The surface of the original plateau, through which the streams have cut, rose "from an altitude of 1,000 feet above sea level at the Ohio River to 2,000 feet above the same datum plane at the Tennessee line" (*8, p. 187*).[2]

Geologically this region is the eastern coal field. The conglomerate or lower portion of the coal measures extends in a strip from 5 to 25 miles wide along the western border. It includes portions of Wayne, Whitley, McCreary, Pulaski, Laurel, Rockcastle, Jackson, Owsley, Lee, Estill, Wolf, Powell, Menifee, Morgan, Rowan, Elliott, Carter, and Greenup Counties. In all, the area of the conglomerate outcrop, or lower "Coal Measures," includes about one-third of the entire field (*5*, p. *1067*). The westward facing escarpment of the Cumberland Plateau, formed by the conglomerate outcrop, presents a barrier between the mountain and the bluegrass regions, which has been compared to a Chinese wall (*8, p. 152*). This situation has exerted a profound influence on the economic and social development of the mountain region.

SETTLEMENT

Settlements in the mountains were not established until 1789 (*17, p. 74*), although settlements in the bluegrass were made as early as 1775. Not only the greater fertility of the bluegrass plains, but Indian hostility as well, operated to retard settlement in the mountains. During the decade, 1790–1800, there was a gradual increase in the number of permanent settlers in the mountains. In 1800, except in the lower Kentucky, Cumberland, and Licking Basins, density of population was less than 2 per square mile. From that time, population moved from the western margin of the mountains slowly up the main river valleys. In 1850 the general density of population

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(Continued from p. 1)

ing in this bulletin and the preparation of the text. Tabulations and summaries of the farm management and of the population data utilized in this bulletin were prepared, respectively, by the Kentucky Agricultural Experiment Station, under the supervision of W. D. Nicholls and H. W. Hawthorne, and by the division of farm population and rural life, under the supervision of C. J. Galpin. For more detailed treatment of special aspects of this study, reference may be made to the following bulletins of the Kentucky Agricultural Experiment Station: Bulletin No. 305, Farm Management and Incomes of Farm Families in Laurel County Kentucky, by W. D. Nicholls and H. W. Hawthorne; Bulletin No. 301, Cost of Living and Population Trend in Laurel County, Kentucky, by Merton Oyler. The basic materials of these bulletins have been freely utilized in developing the present analysis. F. J. Marschner, division of land economics, Bureau of Agricultural Economics, developed a basis for and prepared the maps appearing in the present bulletin. Acknowledgments are also due Willard Rouse Jillson, director of the Kentucky Geological Survey, for assistance rendered Mr. Marschner in this work, and to C. H. Burrage, formerly university forester, Kentucky Agricultural Experiment Station, and Bernard Frank, assistant forest economist, United States Forest Service, who collected the data on farm wood lots.

[2] Italic numbers in parentheses refer to Literature Cited, p. 99.

was from 6 to 18 persons per square mile, and 20 years later, in 1870, the general average was from 18 to 45 to the square mile. By 1900 a density of 18 to 45 prevailed even in the more sparsely settled districts, while an increase from 45 to 90 persons to the square mile had taken place in the coal-mining districts along the upper Cumberland and Big Sandy Basins and had reached 90 and over along the Ohio River.

In 1920 the average density of the 34 mountain counties was about 53 persons to the square mile. If incorporated places having a population of 2,500 or more are excluded, the rural districts of these counties had a population density in 1920 of 48.8 persons to the square mile. Between 1840 and 1900 the increase of population was largely genetic. The development of mining has stimulated immigration since 1900, although some foreigners came in with the advent of the railroads. The foreign population is confined almost exclusively to the mining districts.

The State bureau of immigration, formed in 1880, encouraged immigration to the mountain region. In 1881 colonists from the Canton of Bern in Switzerland settled near Bernstadt (Laurel County). The immigrants began arriving in April, coming in groups of 10 to 40 persons. By 1883 about 900 settlers had arrived.[3]

The Bernstadt Colonization Co. had secured an option on a large acreage of land in Laurel County at $1 an acre. Sales were made to settlers at $3, $4, and $5 an acre. The terms required cash payment of one-fourth of the purchase price and the balance on mortgage at 6 per cent. A few families purchased 200-acre tracts, but the usual range was 20 to 100 acres per family, with the bulk of the purchases ranging from 20 to 40 acres.

The settlers produced berries, small fruits, and vegetables. They planted vineyards and grew grapes, and wine was produced locally.[4] Very few settlers arrived after 1884. After 1886 the coal mines near Pittsburg and East Bernstadt, where wages ranged from $3 to $7 a day, attracted many of the settlers. In 1889, 50 of the settlers migrated to Phillips County, Ark. The colony disintegrated rapidly. In 1927 there were about 150 persons of Swiss descent, mostly farmers, in the neighborhood of Bernstadt. This number included about 15 of the original settlers.

PIONEER ROADS

The early history of transportation in the mountains centers around four main transmontane routes of travel (*17, p. 57*).

The Wilderness road entered Kentucky through Cumberland Gap, following Boone's trace marked out in 1775 northwestward across the rugged plateau to the central bluegrass. The road passed through London at the site of the present courthouse. Just north of London, near the present site of Pittsburg, the road divided. One branch followed Logan's trace through Hazel Patch, Crab Orchard, and Danville to the falls of the Ohio, where the city of Louisville now stands. The other continued northward along Boone's trace through

[3] Verhoeff (*17, p. 28*) states: "There were 440 of these settlers, who had purchased 4,146 acres of colony lands." R. Ott, Bernstadt, Ky., one of the original settlers, gave the information used in the present account.

[4] "In the South (at Strassburg) there were wine-growers from the Upper Rhine, who planted a considerable acreage of grapes. There was also a colony (Pine Hill-Salzburg) in Rockcastle County. All of these immigrants came with the hope of producing wine, garden truck, and cheese, and when their efforts in these directions failed some went into the coal mines, but many left the mountains" (*17, p. 28*).

Richmond and Boonesborough (now Ford in Madison County) to the heart of the bluegrass, where Lexington now stands (*17, p. 82*).

A second pioneer route, the Owingsville and Big Sandy, extended northeastward from Mount Sterling through Owingsville to the Big Sandy River at Catlettsburg where it connected with the Greenbrier road in Virginia.

The third of the main lines was the Mount Sterling-Pound Gap route extending eastward from Mount Sterling to Paintville, thence southeastward through Prestonburg to Pikeville, where the road branched, the southern route connecting with the Virginia roads through Pound Gap and an eastward extension effecting a junction by following the Louisa fork of the Big Sandy River.

The Irvine-Pound Gap route connected with the Wilderness road at Richmond on the west and extended east and southeast through Jackson in Breathitt County and Hazard in Perry County to Sounding Gap. An extension of the road from this point connected it at Pound Gap with the south fork of the Mount Sterling-Pound Gap route.

From 1792 to 1850 the chief traffic on these transmontane roads was livestock. Cattle, hogs, horses, and mules were driven from central Kentucky across the mountain roads to the eastern and southern markets. "The farmers living along the mountain roads exhausted their lands in efforts to furnish a supply of food and forage sufficient for the journey" (*17, p. 98*). The hog drivers furnished a cash market for corn, with the result that the mountain farmers impoverished the land by continuously growing corn on it, and themselves by selling corn at 12.5 to 15 cents a bushel in the fall to obtain cash, only to be compelled to pay 35 to 40 cents a bushel for corn in the spring (*17 p. 146*).

The principal eastern markets were Baltimore and Philadelphia. To the south, Georgia and the Carolinas furnished a market, especially for horses and mules, which were driven along the Wilderness road through Cumberland Gap on their way to the southern markets (*17, pp. 98–99*). The peak of this transmontane traffic was reached in the period from 1830 to 1840 (*17, p. 126*).

In spite of steepness and frequent washouts, the mountain roads, up to about 1830, were as good as, and sometimes superior to, those of central Kentucky. But between 1830 and 1850 macadamized roads, built and successfully operated on the turnpike system by joint-stock companies, had surpassed the mountain routes. By 1848 the Wilderness road "had lost practically all significance as a transmontane route and was of mere local importance" (*17, p. 126*). By 1880 salt and livestock traffic, formerly the chief source of revenue, had practically disappeared. It was in the latter year that the tollgates on the Wilderness road were abolished, and, although nominally under the supervision of the State until that time, the road has been controlled since 1844 by the counties through which it extends (*17, p. 125*).

Two principal factors contributed to the decline in the importance of the mountain routes after 1850 (*17, p. 100*). Improved methods of transportation on the Ohio River caused the river route to absorb much of the traffic and led to the establishment of large packing houses in the principal river cities. The packing houses cut off the volume of livestock driven on foot to the eastern markets, thus elimi-

nating the principal source of revenue of the mountain routes and severing the chief line of communication between the mountain population and the "settlements."

A second factor in this decline was the rapid increase of railway mileage in the Ohio-Mississippi Valley about 1853, and the consequent shift of grain and livestock farming from the Ohio Valley to the Northwest. Along with this movement came the shift in the center of the meat-packing industry from Cincinnati to Chicago.

The mountain routes were abandoned. For more than half a century, after 1850, the mountain people were isolated to a degree that left them practically untouched by the economic and social ferment of the period.

RAILROADS

Exploitation of the natural resources [5] of the mountain counties, particularly of the coal fields, gave the chief impetus to the penetration of the mountain barrier by the railroads.[6] The rugged character of the country makes railway construction and operation expensive. Railway facilities are, therefore, limited in many of the mountain counties, and a few counties have no railroad within their borders. Lack of railroad facilities, together with poor wagon roads, always difficult and sometimes impossible to travel, greatly impede the movement of persons and goods in the more rugged sections. Economic and social isolation has been the inevitable consequence of this situation.

The railroads penetrated the mountain region through breaches made by rivers in the plateau escarpment. Six main lines now enter or cross the coal field (*8, p. 190*). Laurel County is traversed from north to south, a distance of 15 miles, by the Louisville, Knoxville, & Atlantic division of the Louisville & Nashville Railroad. Junction at East Bernstadt is made by the Rockcastle River Railroad, a short spur, extending through the northern part of the county to the Jackson County line. The influence of topography in determining the course of travel in the mountain region is illustrated by the fact that the railroad follows closely the old Wilderness road through Laurel County and southward, while to the north the railroad routes divide, along the courses of the pioneer roads, one branch following the Boone trail to the bluegrass, the other passing through Hazel Patch, Crab Orchard, and Danville along the route followed by the Indians and the pioneers to the falls of the Ohio River.

TIMBER

The area of Kentucky is 25,715,840 acres The original forest area was 24,320,000 acres. In 1920 about 9,400,000 acres of forest land remained. State and national forest lands aggregated 41,284 acres in 1925. A large part of the woodland acreage is included in farms.

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[5] The principal natural resources of Laurel County are timber and coal. Timber resources of the county are discussed in a subsequent section of this bulletin. The annual output of coal in Laurel County is now approximately 150,000 tons and the amount of labor employed is proportionately small. Only 22 farm families, among the 203 records summarized, reported receipts from mining coal in 1927, and five families reported hauling coal as a source of cash income. Supplementary receipts from coal mining would amount approximately to $20 a family if distributed equally to the 203 families included in the farm business summary. This is a cash item of some importance in an area where the annual cash income of nearly half the families is under $500 and averages only $319. But the opportunities afforded by coal mining in Laurel County either for full-time or part-time employment are limited, and any significant local expansion of the industry is improbable.

[6] "Railroad building began in 1856, but made no headway until between 1870 and 1890. Since then progress has been slow, and confined until recently to marginal counties. The explanation is found in the fact that none of the natural resources have been of sufficient commercial value in the past to warrant the large expenditures of labor and capital required by such schemes" (*17, p. 57*).

Approximately 20 years prior to the date (1927) of this study, it was estimated that 5,664,272 acres, or approximately 80 per cent, of the Kentucky mountain region was forested and that the total stand was about 18,000,000,000 board feet (*4, pp. 133–135*). The original hardwood stand was probably two and a half times as great. Lumber production in Kentucky reached a peak in 1907 (*14*). In some of the mountain districts, however, the peak of production was not reached until a later date, when railroad development made the stands accessible (*4, p. 11*). The opening of the coal mines expanded the local market for forest products. The forested areas were rapidly depleted.

LARGE HOLDINGS

Although a large part of the forested area of eastern Kentucky is in farms, large holdings are not uncommon, especially in the counties in which coal or other mineral resources exist. Some renter farmers and occasionally some squatters are found on these large tracts, but the land is principally in timber and is held in private ownership as a rule, primarily for the present or potential value of its mineral resources. The importance of conserving the timber on these tracts is, however, receiving increased attention, particularly in the matter of protecting the stands from fire. Data were obtained for 169 tracts of 1,000 acres and over, located in eastern Kentucky. Of this number, the distribution by counties was obtained for 122 tracts. These 122 tracts were distributed in 17 counties, including in addition to those shown in Figure 1 the following: Boyd, Carter, Greenup, Johnson, McCreary, and Pulaski. Of the 122 tracts, Letcher County had 26, Clay and Whitley Counties 14 each, McCreary 13, and Bell 11. Figure 1 is based on a map of fire-protection areas,[7] but does not show the boundaries of individual holdings.

Some idea of the approximate size of large holdings in most of the southeastern counties is given by figures[8] obtained from county seats. Tracts under 1,500 acres were most frequently listed, and approximately half the number of tracts listed was included in the three acreage groups below 2,500 acres. The remaining 50 per cent was distributed over a wide range, from 2,500 to 50,000 acres and over. Nine tracts of 1,000 acres and over, having a total area of 36,243 acres, including one holding of 21,277 acres, were listed in Laurel County. The 8 remaining tracts ranged in area from 1,000 to 4,000 acres and averaged 1,871 acres. The 9 tracts averaged 4,027 acres in area. With the exception of these 9 tracts there were only 4 tracts of 500 acres and over, ranging from 570 to 856 acres, 4 ranging from 300 to 400 acres, and 19 ranging from 200 to 275 acres. Approximately 1 acre in every 8 of all land in the county and approximately 3 acres in every 10 of the land not in farms was in privately owned tracts of 1,000 acres and over. These large holdings were chiefly in the western section of the county, districts 4 and 5.

[7] Furnished through the courtesy of the Kentucky State Department of Forestry.
[8] Furnished through the courtesy of S. D. Suiter, district forester, Pineville, Ky.

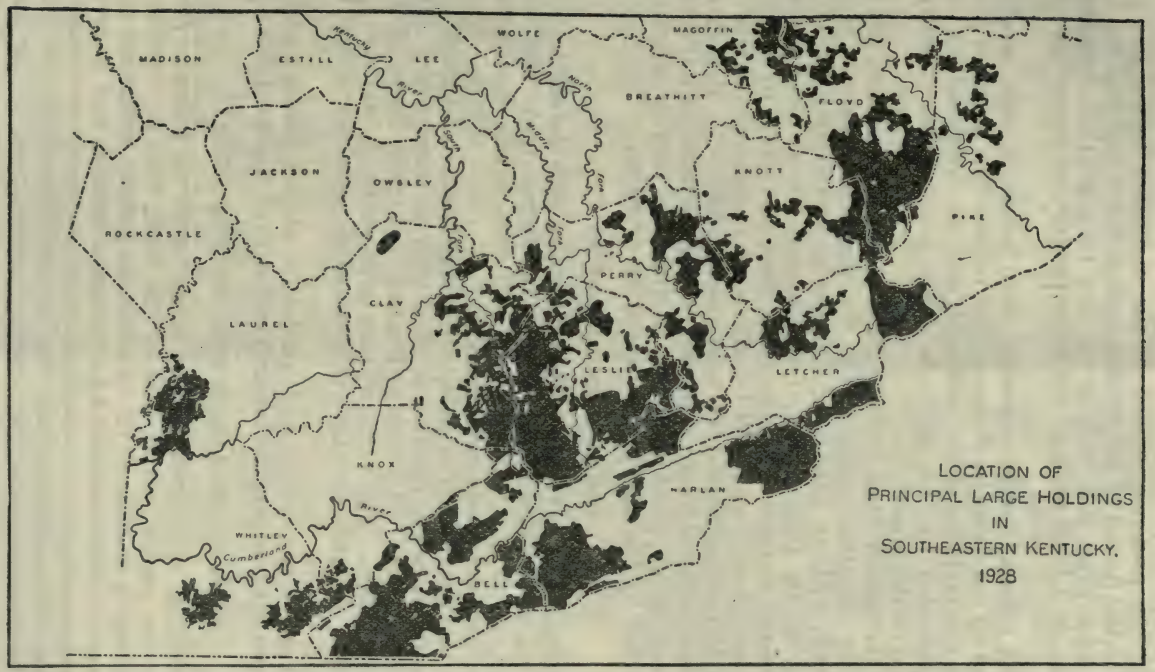


FIGURE 1.—Although a large part of the forested area of eastern Kentucky is in farms, large holdings are not uncommon, especially in the counties containing coal or other mineral resources. Such tracts are held in private ownership as a rule, primarily for the present or potential value of the minerals

COAL

The Kentucky mountain region is a part of the great Appalachian coal field. The entire region is underlain by coal, but there is great variation in the number and thickness of the seams and in the quality of the coal (*3, p. 121*).

Although the presence of coal in the mountain region has been known since the period of the earliest explorations, and coal has been produced since 1828, it is only in the last 15 years that commercial exploitation on a large scale of the more productive seams has taken place.

Until the railroads were extended into the mountains, coal was transported on the rivers by flatboats and rafts. The presence of coal stimulated the building of the railroads, and the improved transport facilities provided by the railroads made possible the commercial exploitation of the mines.

During the period from 1925 to 1928 coal was commercially produced in 20 counties embraced in the mountain region. Harlan County leads with an annual production approximating 12,000,000 tons, followed by Pike, Perry, Letcher, and Floyd Counties with annual outputs ranging approximately from 5,000,000 to 8,000,000 tons, and by Johnson and Bell Counties, which produce annually in excess of 1,000,000 and 2,000,000 tons, respectively (*7*). In a number of the other counties the annual output of coal is a factor of importance in furnishing employment to labor, although, of course, not on the scale provided by the heavy coal-producing counties.

OTHER MINERAL PRODUCTS

Oil was discovered in Kentucky in connection with the salt industry. The first oil strike was made in 1819 in Wayne (now McCreary) County (*8, p. 287*). Davis (*3, p. 128*) lists seven commercially productive sections in the mountains.

Commercial production of petroleum dates from about 1880. The peak of production was reached in 1919 with an output of 9,226,473 barrels in that year. The total estimated production up to 1927 was 80,000,000 barrels. The value of this large output is enormous, but the benefits derived by the oil-producing counties have been questioned.[9]

Natural gas, clays, sands, and gravel are also of present and potential importance among the natural resources of the mountains (*13*).

OBJECTIVES AND SCOPE OF THE STUDY

The principal objectives of the study were as follows: (1) To determine the present major uses of the land, that is, whether for crops, pasture, or woodland; (2) to relate the present utilization of the land to basic physical conditions for the areas studied, and to generalize these relationships, as far as possible, to the county as a whole; (3) to trace the relationship between the physical characteristics of land and (*a*) the distribution of land among various uses, (*b*) the size of the farm business, (*c*) the amount and sources of farm and other in-

[9] Davis (*3, p. 130*) observes that "it is doubtful whether the oil producing counties have benefited directly and permanently to any considerable extent. In many cases, the original holders of the land derived little or no financial profit from the discovery of oil, the returns from the exploitation of the resource going outside the area. With the depletion of the pools and the abandonment of the wells, the economic structure collapsed, leaving the region in worse condition than it was prior to the discovery of oil."

come, (*d*) the sources and value of the family living, and (*e*) the composition and characteristics of the population; and (4) to outline on the basis of the foregoing analysis a land-utilization program designed to

FIGURE 2.—LOCATION OF FARMS VISITED

The data of the study are based on farm-management and family-living records obtained from 203 farms, records for individual fields from 52 farms, wood-lot records from 49 farms, together with supplementary data relating to population and to unoccupied farms. The area south of London is referred to as the south area and the area northeast of London as the north area. (Topography based on United States Geological Survey. Cultural features based chiefly on sketches made in the field and on data supplied by the Kentucky Geological Survey.)

secure the optimum adjustments of the mode of living and of the social and economic institutions of the area.

The location of farms visited is shown in Figure 2. The area covered includes eight school districts, Old Union, McGill, and Wyan,

lying south of London (south area), and Old Salem, Pleasant View, Taylor, Twin Branch, and Long Branch, lying northeast of London (north area).

In 1927 the eight school districts covered by the study contained 17,642 acres of land in farms. This acreage was distributed among 277 farms, an average of 63.7 acres per farm. The total farm population was 1,259 in 1928. This represents a density of 45.7 persons per square mile for the farm population of the eight school districts.

The farm-business and family-living summaries contained in this bulletin are based on records of 203 farms, of which 83 were in the south area and 120 were in the north area. Farm-business records were obtained from 212 farms and family-living records from 227 farms. The farm-business and family-living records were for identical farms in 205 cases.

Schedules covering the physical characteristics of fields, together with a record of costs incurred and yields obtained in the production of crops over a 3-year period, were obtained from 52 farms, of which 22 were in the south area and 30 were in the north area. The same schedule provided data on the utilization and costs of pastures. Farm-business and family-living data were obtained for 51 of these farms. Data relating to the resources and utilization of farm wood lots were obtained from 49 farms, of which 31 were in the south area and 18 in the north area. The crop and wood-lot schedules were for identical farms in 35 cases.

For farms for which no farm-business record was available supplementary data were obtained to show the major uses of the land in 1927 and the occupancy of the farm for the preceding 10 years.

DESCRIPTION OF LAUREL COUNTY

GENERAL CHARACTERISTICS

Laurel County belongs to the double tier of counties comprising the western border of the Kentucky mountains. The counties of this western group, about 18 in number, have been characterized, in general, as the "ridge top" settlements in contrast to the "creek bottom"[10] settlements typical of the counties further east (*3, p. 14*).

The ridge-top settlements comprise about one-third of the area of the Kentucky Mountains. The economic and social aspects of land utilization in Laurel County are generally significant for, and broadly applicable to, the western third of the Kentucky Mountain region.

The present study proceeded on the assumption, therefore, that a detailed study of the economic and social aspects of land utilization in typical areas in Laurel County would yield results significant not only for the areas studied, but also for Laurel County and other counties in the Kentucky Mountains where conditions are similar, particularly the counties of the western group belonging to the ridge-top settlements.

The surface of the London quadrangle,[11] within which most of Laurel County lies, is about 1,200 feet above sea level. Knobs such

[10] A study in Knott County, Ky., which is in the creek-bottom settlements, was made by the Kentucky Experiment Station in cooperation with the United States Department of Agriculture in the summer of 1930.

[11] A special feature of the area included in the London quadrangle is that "the upper plain and the steep escarpment are lacking." This feature is due to the fact that at this point "the hardest rocks do not reach outward to the margin of the field" (*3*).

as Frazier Knob, Laurel Hill, and Raccoon Mountain (fig. 2), east of London, rise 300 feet or more above the general level. These are regarded as vestiges of the original plateau, the soft surface rock of which was removed, leaving the present structural plain formed by a hard cap of conglomerate into which the streams have cut to form the present rugged topography (*2*).

CLIMATE AND RAINFALL (15)

Precipitation in eastern Kentucky is obtained chiefly from the storms which move northeastward from the western Gulf region. Records of monthly and annual mean precipitation at London, in Laurel County, and at four other stations in counties close to Laurel—Burnside and Eubank, Pulaski County; Manchester, Clay County; and Williamsburg, Whitley County—are available. These records show that the amount and distribution of precipitation are well suited to the growing of crops.

Mean annual temperatures at Eubank and at Williamsburg are 55.1° and 57.5° F., respectively. The warmest weather occurs in July and the coldest in February. The mean maximum temperature in July is 86.7° at Eubank and 88.5° at Williamsburg. The mean minimum temperatures at the same stations for February are 24° and 27°, respectively. The climate is mild and pleasant, although days of relatively extreme heat or cold occur. Frost data for Eubank and Williamsburg indicate a growing season of 177 and 189 days, respectively.

SOILS

The soils of Laurel County are chiefly residual, alluvial deposits being confined to narrow strips along the larger streams. These soils have been formed by the disintegration of the sedimentary rock. The residual soils of the county vary with the rock strata from which the various soil types were developed. Although no soil survey has been made in Laurel County, soil characteristics can be inferred, in general, from the nature of the rock strata. (Pl. 1.)

The rock formations of the portion of Laurel County shown in the London quadrangle belong principally to the Pennsylvanian series laid down in the Carboniferous period. Most of the area in the vicinity of London has soils derived from the Breathitt formation. Southeast of London the Corbin conglomerate at the top of the Lee formation appears, although the Breathitt formation predominates here also. Since the relation of these types to land utilization is hereafter considered, a brief description of each type is essential.

The Breathitt formation is composed of sandy shale and coarse ferruginous sandstone. The topography is characteristically hilly, with gentle slopes and rounded summits. On the shale outcrop the soil is fair, but soils derived from the sandstone are poor (*2*).

The Corbin conglomerate lentil is a cap of conglomerate and of coarse pink sandstone overlying the Lee formation. Clifflike topography and light, sandy soils are characteristic of the Corbin formation. An important phase of the DeKalb fine sandy loam is derived from the pink sandstone of the Corbin conglomerate. The DeKalb fine sandy loam is deficient in organic matter and is poorly adapted to agricultural uses. It is usually found on the knobs and ridges (*1*).

The Lee formation is composed of "sandy shale and sandstone with a few seams of coal" (*2*). Ridges and gently rolling uplands are characteristic of the topography. The soil survey of Rockcastle County, which adjoins Laurel County (*1*), found soils of the DeKalb series derived from the Lee formation. According to this survey, the sandstone and fine sandy shale of the Lee formation give rise to the DeKalb fine sandy loam, which is characteristically gray, but sometimes yellowish brown in color. Small sandstone pebbles and sandy shale are mixed with the soil and scattered over the surface.

Along the slopes where the sandstone of the Lee formation has been removed, this formation produces the DeKalb shale loam. This soil type is extensively developed in Rockcastle County, and extensive areas of the Lee formation, from which the type is derived, are shown on the London quadrangle in the northern and western parts of Laurel County. (Pl. 1.) But the Lee formation is exposed only to a limited extent in the vicinity of London. In the north area, farms lying along the Raccoon and the Little Raccoon Creeks include soils derived from the Lee formation, and on these farms it is probable that the DeKalb shale loam predominates. The rolling-to-rough topography is a limiting factor in the use of the land for the growing of cultivated crops, although the soil is fairly productive.

The DeKalb shale loam consists of a silt loam about 10 to 12 inches deep, underlain by compact, silty clay loam, grading into silty clay. In color the soil is usually light brown, ranging from a yellow to a brown. Erosion has progressed further on the yellow soils. Sand is sometimes present, and shale and sandstone particles in the soil and on the surface are common. The soil is derived from the weathering of the shales of the Lee formation.

The DeKalb sand and the DeKalb silt loam are typically ridge-top soils derived from the sandstones and shales of the Lee formation. The former type is loamy, forming a loose and incoherent soil which is low in organic matter and retains water poorly. The DeKalb silt loam is gray to light brown in color. Its organic content is higher that that of the lighter, sandy soils, but the soil is not so favorably regarded as the shale loam lying on the slopes. In the Rockcastle County survey only a limited area of these soils was found.

In the eastern portion of Laurel County the Breathitt formation, lying on top of the Corbin conglomerate, or on top of the Lee formation, is chiefly exposed. (Pl. 1.) In the western portion extensive areas of the conglomerate cap overlying the Lee formation have been exposed, and over a large part of this section the erosional process has gone further, removing the conglomerate cap from most of the area and leaving the Lee formation exposed. Along the Rockcastle River and at scattered points yet deeper Carboniferous strata have been uncovered in channels cut by the streams.

DRAINAGE

The Rockcastle and Laurel Rivers, tributaries of the Cumberland, drain the northern and southern portions, respectively, of Laurel County. The valley of the Rockcastle is narrow and bordered by precipitous sandstone or conglomerate cliffs. Except in its upper reaches, the Laurel, like the Rockcastle River, has cut through the conglomerate, forming steep walls from 100 to 400 feet high (*2*).

THE TILIZATION

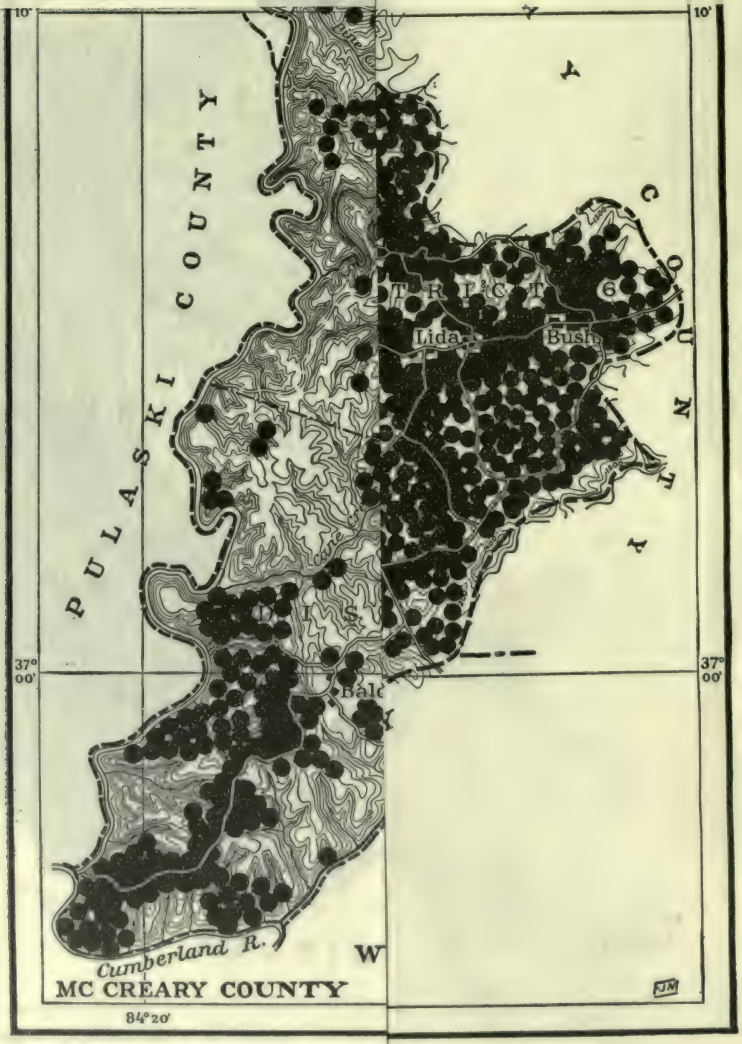


FIGURE 3.—Plate 1

MAJOR USES OF THE LAND

The foregoing description indicates that the physical characteristics of the land have had a predominating influence on the economic and social history of the Kentucky Mountain region.

Data of the census on the utilization of land in Laurel County in 1924 are shown by districts in Table 1. Figure 3, based on Table 1, shows the distribution of land in farms. The topographic and geologic features of Laurel County shown in Plate 1, and the associated factors discussed in the text, are closely related to the distribution of land in farms shown in Figure 3 and suggest a preliminary basis for dividing the county into four main sections, each characterized by essentially different conditions affecting the use of the land. The marked contrast in the development of the rock strata of western and eastern Laurel County is shown by Plate 1. To a lesser degree there is also a contrast in topography between the two portions, the western part of the county being the more highly dissected and rugged.

TABLE 1.—*Farms and farm acreage, by districts, Laurel County, Ky., 1925*

Item	District 1	District 2	District 3	District 4	District 5	District 6	District 7	Total
Number of farms	290	482	484	299	394	566	294	2,809
	Acres	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
Approximate land area	16,783	35,728	37,638	66,008	55,989	52,126	18,088	[1] 282,360
All land in farms	15,822	23,275	31,656	21,415	28,036	36,359	10,612	167,175
Average per farm	54.6	48.3	65.4	71.6	71.2	64.2	36.1	59.5
Crop land:								
Harvested in 1924	4,707	7,592	12,683	4,162	6,005	10,736	3,567	49,452
Crop failure	74	10	0	25	95	37	14	255
Idle or fallow	1,510	1,731	440	1,339	2,471	1,857	629	9,977
Total	6,291	9,333	13,123	5,526	8,571	12,630	4,210	59,684
Pasture land:								
Plowable pasture	3,102	5,621	7,813	2,275	2,093	1,803	785	23,492
Woodland pasture	659	129	490	1,450	529	890	837	4,984
Other pasture	1,427	523	511	306	671	5,846	405	9,689
Total	5,188	6,273	8,814	4,031	3,293	8,539	2,027	38,165
Woodland not used for pasture	2,439	6,249	3,948	10,673	12,061	6,185	3,054	44,609
All other land in farms [2]	1,904	1,420	5,771	1,185	4,111	9,005	1,321	24,717

Compiled from the Census of Agriculture, 1925 (*16*).

[1] The area of Laurel County shown is the sum of the areas of the several districts. These areas were computed by the use of a planimeter. The U. S. Census of Agriculture, 1925, and the Kentucky Geological Survey report, respectively, 286,080 acres and 282,982 acres as the area of Laurel County.

[2] According to the definition of the census, this includes "all rough, swampy, or waste land neither in forest, pasture, or crops, and also the land occupied by buildings, barnyards, feed-lots, roads, etc."

THE WESTERN SECTION

The rough topography characteristic of the western section (districts 4 and 5) is distinctly unadapted to agriculture and, in addition, the light, sandy soils derived from the conglomerate sandstone, which is extensively developed in this section, are deficient in organic matter and are unproductive. This section embraces 43.2 per cent of the area of the county, of which district 4 includes 23.4 per cent and district 5, 19.8 per cent. In the northern part of this section (district 4) only one-third (32.4 per cent) of the land area was in farms in 1925. (Table 2 and Fig. 3.) Of the land in farms, 56.6 per cent was woodland. Woodland in farms comprised, therefore, approximately 18.3 per cent of the total land area of the district. The area not in farms

is principally forest and woodland, and these classes of land comprised, therefore, approximately 85.9 per cent of the total area of district 4, of which 18.3 per cent was in farms and 67.6 per cent was not in farms. (Fig. 4.)

TABLE 2.—*Percentage distribution of farms and acreage, by districts, 1925*

Item	District 1	District 2	District 3	District 4	District 5	District 6	District 7	Total
DISTRIBUTION WITHIN THE COUNTY								
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Number of farms	10.3	17.2	17.2	10.6	14.0	20.2	10.5	100.0
Approximate land area	5.9	12.7	13.3	23.4	19.8	18.5	6.4	100.0
DISTRIBUTION WITHIN THE DISTRICT								
Percentage of total land area in farms	94.3	65.1	84.1	32.4	50.1	69.8	58.7	[1] 59.2
All land in farms:								
Crop land	39.8	40.1	41.5	25.8	30.6	34.7	39.7	35.7
Pasture land [2]	28.6	26.4	26.3	12.1	9.8	21.0	11.2	19.8
Woodland [2]	19.6	27.4	14.0	56.6	44.9	19.5	36.7	29.7
All other	12.0	6.1	18.2	5.5	14.7	24.8	12.4	14.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Crop land:								
Harvested in 1924	74.8	81.3	96.6	75.3	70.1	85.0	84.7	82.9
Crop failure	1.2	.1	0	.5	1.1	.3	.3	.4
Idle or fallow	24.0	18.6	3.4	24.2	28.8	14.7	15.0	16.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pasture land:								
Plowable pasture	59.8	89.6	88.6	56.4	63.5	21.1	38.7	61.5
Woodland pasture	12.7	2.1	5.6	36.0	16.1	10.4	41.3	13.1
Other pasture	27.5	8.3	5.8	7.6	20.4	68.5	20.0	25.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Crop land harvested, 1924:								
Corn	43.2	39.3	36.3	49.2	51.7	48.2	40.1	43.2
Small grains	14.2	11.6	17.9	12.8	12.2	9.2	15.2	13.4
Hay [3]	37.7	30.4	38.0	24.3	28.8	33.1	28.8	32.8
Tobacco	.4	.5	2.5	.5	.5	.5	1.2	1.1
Sorghum	.6	6.4	.1	3.7	1.2	1.1	1.4	1.8
Potatoes	1.1	2.1	.9	1.7	2.0	2.2	2.9	1.7
Sweetpotatoes	.7	.8	.6	.4	.5	.6	1.1	.7
All other [3]	2.1	8.9	3.7	7.4	3.1	5.1	9.3	5.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Compiled from the Census of Agriculture, 1925 (*16*).

[1] The census shows that land in farms in 1925 amounted to 58.4 per cent of the total area, instead of 59.2 per cent. For an explanation of this difference see footnote 1, Table 1.

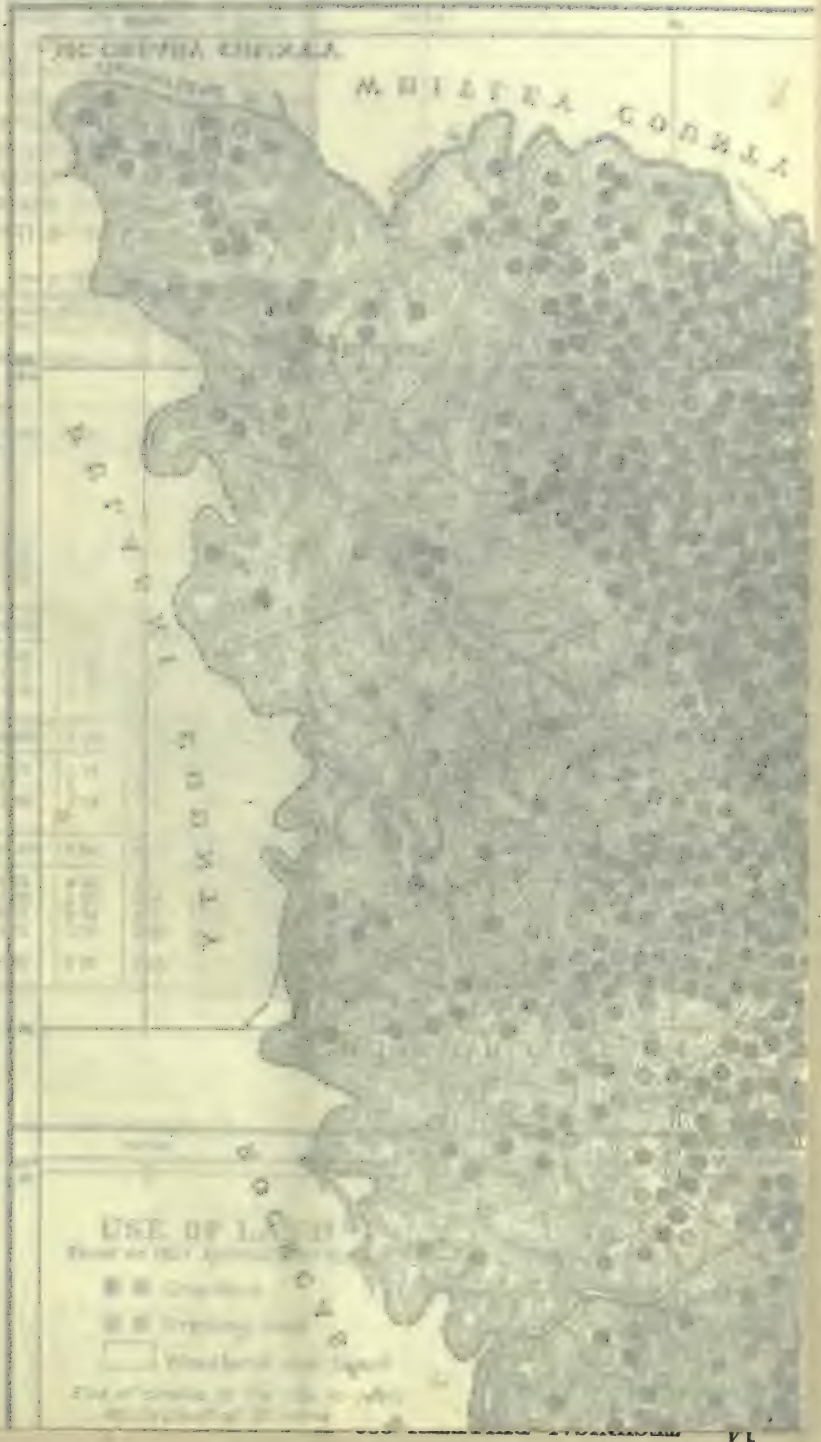
[2] Woodland pasture, unless otherwise noted, will always be included in woodland, not in pasture land.

[3] The census shows a total of 16,774 acres in hay. This total includes 557 acres of annual legumes cut for hay for which figures by districts were not obtained. In computing the percentage distribution of the crop acreage, these 557 acres were included in the acreage of all other crops, not in the acreage of hay.

In district 4 crop land represents only 25.8 per cent of the land in farms, the lowest proportion represented by crop land among the districts in the county. Although the average acreage per farm (71.6 acres) is the largest among the districts, the average amount of crop land per farm (18.5 acres) is smaller than in any other district, except one. Farmers in district 4, although having more land per farm than in other districts, have less land that is worth having from an agricultural standpoint. Moreover, one-fourth of the crop land in this district was idle or fallow in 1924. A brief account has been given (p. 3) of the effort to establish a colony on the conglomerate and sandstone ridges around Bernstadt and of the emigration of most of

FIGURE 4.—Uses of land are influenced, and in the availability of employment off the farm

88114°—32. (Face p. 14.)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USE OF LAND

the settlers and the rapid disintegration of the colony. Apparently, the ridges are too narrow, the soils too poor, and the slopes too steep to permit generally successful farming, particularly since the country is isolated by lack of roads.

The physical features of district 5 are also unfavorable to farming. Compared with district 4, however, the ridges in district 5 are broader and more extensive, the slopes, in general, are less precipitous, and the Breathitt formation, which affords a better soil foundation than the Corbin conglomerate, occupies a greater proportion of the area. As might be expected, therefore, a larger proportion (50.1 per cent) of the land area of district 5 than of district 4 was in farms in 1925. The acreage per farm (71.2 acres) averaged about the same as in district 4, but crop land averaged 21.8 acres per farm, which compared favorably, in amount at any rate, with the other districts of the county. But the fact that 28.8 per cent of the crop land in this district was idle or fallow in 1924 suggests that much of the land was of poor quality. Forest and woodland in farms comprised 22.5 per cent, and land not in farms (principally forest and woodland) 49.9 per cent of the land area of this district.

THE NORTHERN SECTION

The boundaries of district 3 roughly delimit the northern section. Geologically, it is differentiated by the fact that over a large part of the area the rock strata of the Breathitt formation have been removed, permitting extensive development of the Lee formation. This development in the northern section, unlike the situation in the western section, is not associated with exposures of the Corbin conglomerate, which is a hard conglomerate cap overlying the Lee. The fact has a twofold importance. In the first place, the relatively uniform exposure of the Lee formation produces broad ridges, moderate slopes, and gently rolling uplands, interspersed with stretches of bottom land along the creeks, which are better adapted to farming than are the relatively steep slopes and more rugged topography of the western section. (Pl. 1.) In the second place, from the rock strata of the Lee formation is developed the DeKalb shale loam, which is distinctly superior to the light, sandy soils characteristic of the Corbin conglomerate.

Of the total area of the district, land other than forest or woodland (principally crop and grazing land) comprised 72.3 per cent, woodland in farms 11.8 per cent, and land not in farms (principally forest and woodland) 15.9 per cent.

Land in farms comprised 84.1 per cent of the area of the northern section (district 3) in 1925, although much of the topography is rough. Farms averaged 65.4 acres per farm, but the amount (27.1 acres) of crop land per farm averaged higher than in any other district. Only 14 per cent of the area of land in farms was woodland. The spur-line railroad extending from East Bernstadt to the Jackson County line, along the valley of Little Raccoon Creek, relieves to some degree the isolation of adjacent farmers. Roads in the neighborhood are unimproved and often impassable. Further west, a north-south section of the Dixie Highway, passing through Victory and Mershons, supplements the transport assets of the district.

THE CENTRAL SECTION

Districts 1, 2, 6, and 7 offer little contrast in the character of the rock strata exposed. The Breathitt formation predominates, with considerable areas of the Corbin conglomerate exposed in each district, especially in district 2. Nevertheless, districts 1, 2, and 7, which are here designated as the central section, have certain features in common that differentiate them from district 6. Specifically, they are traversed by the only main-line railroad and the only through highway in the county. Consequently, the most populous towns in the county, including the county seat, are found within their borders. Coal-mining development in Laurel County, also, has been confined to these districts. A number of mines are located in district 7 along the Rockcastle River Railway, in the vicinity of East Bernstadt. These facts are enumerated because of their bearing on special features characterizing the use of land in these districts.

Farms are smaller than in other districts (Table 1), averaging 54.6 acres, 48.3 acres, and 36.1 acres in districts 1, 2, and 7, respectively. More farms in districts 1 and 7 are located on improved roads. District 2 is worse off in this respect than district 5, although nearness to railroad station and paved highway affords to the former district transport facilities superior to those of the latter. Farm real estate values in districts 1, 2, and 7 also average higher than in other districts. (Table 3.) The value per acre of land and buildings in district 7 is nearly four times as great as that in district 4. In district 2 the value per acre of land and buildings is twice, and in district 1 three times, as great as the value in district 6. Values in district 3, however, are equal to those in district 2. In districts 1 and 7, adjacent to East Bernstadt and London, respectively, the average investment per farm in implements and machinery is relatively high, compared with other districts. The same statement applies to the average mortgage debt per acre. Table 3 shows, however, that as a farming area district 3 compares favorably with the districts in the central section.

In average crop values per acre, farm population per square mile, farms reporting expenditures for feed, and value of dairy products per farm, district 3 ranks well to the front or leads the other districts. Attention has already been called to the superior quality of the soil associated with the Lee formation, which is extensively developed in district 3. Another factor in the relative prominence of district 3 as a farming area is indicated by data obtained in the study. Farms of the south area were located in districts 1 and 2 and farms of the north area were located in districts 3 and 6. It is interesting to find that of the 203 farms included in the farm business summary only 33.7 per cent of the operators in the south area depended mainly on farming for a livelihood, in contrast to 51.7 per cent of the operators in the north area. Apparently, because of better roads, nearness to town, and similar factors, there is a greater tendency in the south area to utilize farms primarily as residence sites, and to rely to a greater extent on outside employment as a principal source of income.

TABLE 3.—*Agricultural importance of the several districts as indicated by specified items, 1925*

Item	District 1	District 2	District 3	District 4	District 5	District 6	District 7	All districts
Value of harvested crops per acre of crop land, 1924—dollars	19	23	28	15	16	21	26	22
Value of land and buildings, per acre—dollars	36	24	24	10	14	12	39	20
Value of land excluding buildings, per acre—dollars	22	16	17	7	10	10	22	14
Value of implements and machinery, per farm—dollars	128	67	87	51	56	47	119	75
Farms reporting mortgage debt:								
Mortgage debt, per acre—dollars	14	7	7	5	4	6	9	8
Ratio of debt to value—per cent	26.2	20.6	27.0	46.5	19.8	41.2	29.9	27.8
White farm population, per square mile—number	59	42	45	15	21	36	40	32
Farms located on unimproved dirt roads—per cent	28.3	64.7	90.9	99.3	56.9	98.2	48.6	73.1
Farms reporting expenditures, 1924, for—								
Feed—per cent	61.0	72.0	70.0	51.8	38.3	46.5	69.7	58.4
Fertilizer—do	63.4	48.3	57.2	47.5	48.5	51.2	33.3	50.4
Labor—do	14.8	37.8	12.6	13.7	9.1	6.4	9.2	15.2
Cows milked, per farm, 1924—number	1.97	1.74	2.26	1.79	1.34	1.74	1.36	1.76
Milk produced, per cow, 1924—gallons	329	472	332	303	346	204	304	326
Value of dairy products, 1924:								
Butter made on farms—dollars	14,491	29,604	15,984	11,037	12,488	15,595	8,494	107,693
Butterfat sold—do	1,488	209	2,096	2,375	487	292	35	6,982
Cream sold—do	1,326	7,212	17,066	120	1,878	60	2,044	29,706
Whole milk sold—do	1,487	7,203	791	0	8	390	1,235	11,114
Total—do	18,792	44,228	35,937	13,532	14,861	16,337	11,808	155,495
Per farm—do	65	92	74	45	38	29	40	55
Eggs produced, per farm—dozen	90	87	130	76	87	86	70	92

Compiled from the Census of Agriculture, 1925 (*16*).

In district 1 a very high proportion of the land is in farms (94.3 per cent), principally because of fairly even topography, relatively good roads, and nearness to London. Districts 2 and 7 include considerable rough land which tends to reduce the ratio of land in farms to all land in these districts, and to increase the ratio of woodland to all land in farms, in comparison with district 1. Forest or woodland comprises 24.2 per cent of the area of district 1, 52.7 per cent of district 2, and 62.8 per cent of district 7.

THE EASTERN SECTION

The eastern section (district 6) presents a rough topography, marked by such prominences as Raccoon Mountain and Laurel Hill in the northern portion, and by broad ridges and less precipitous slopes in the southern part. No railroad traverses the section. In the northern part there is no road worthy of the name, and in the southern part the main road passing through Lida and Bush and connecting London and Manchester, the county seats of Laurel and Clay Counties, respectively, was in very poor condition in 1928. To some extent, as previously noted, the rough topography characteristic of the northern part of the eastern section differentiates it from the central section (districts 1, 2, and 7), but a more significant difference between the eastern and the central sections is the relatively greater degree of isolation of the former, because of lack of roads. To reach

the railroad station at London from points along Slate Lick and Raccoon Creeks, with a team hauling a light load, is an arduous undertaking. The census shows that 98.2 per cent of the farms in this district in 1925 were located on unimproved dirt roads. (Table 3.)

District 6 and parts of district 3 are preeminently the areas where cropping of the slopes has left a waste of wornout, heavily eroded fields. There is less waste land in district 3, because of the relatively large amount of bottom land in that district. But the "all other land" classification of the census includes 18.2 per cent of the land in farms in district 3, which is higher than the figure for any other district except district 6. In district 6 nearly one-fourth of the land in farms is classed as "all other land," representing principally eroded, barren, or "filth"-covered [12] hillsides. (Table 2.)

Average farm values of land and buildings, implements and machinery, and dairy products are lower than in any other district, except districts 4 and 5. Average crop values per acre are also comparatively low in district 6, although district 1, in addition to districts 4 and 5, makes a poorer showing in this respect than does district 6.

In district 6 woodland in farms comprises 13.6 per cent and land not in farms, which is principally forest and woodland, 30.2 per cent of the area of the district.

Data on the major uses of the land obtained in the study cover five school districts [13] representing the north area and three school districts [14] representing the south area. In these school districts the use of all land in farms in 1927 was ascertained regardless of whether the farms were operated in that year. Detailed data on land use and land characteristics were also obtained from 52 farms, 30 of which were located in the north area and 22 in the south area.

To facilitate comparison, the percentage of farm land in each major use in Laurel County and in certain districts, as shown by the 1925 Census of Agriculture (*16*), is presented in Table 4, together with figures for identical items based on the data of the survey. The data of the census relate, of course, to the year 1924, whereas those of the survey relate to the year 1927. This may account, in part, for differences in the proportion of land in different uses shown by figures from the two sources. The census data also cover a larger area than the data of the survey. But these circumstances do not account for certain discrepancies which, obviously, are due to other causes. For example, the proportion of "other land" shown by the census for districts 3 and 6 is much larger than the corresponding figures of the survey for the north area, which is included in these districts. Most of the rugged land of the north area which was placed under the "other land" classification of the census, was, in the survey, classed as pasture or woodland. The large proportion of crop land shown by the data for 52 farms is probably due principally to two facts. These records covered the years 1926, 1927, and 1928, and any field cropped in that period was counted as crop land, although it may have been pastured in 1924 or in 1927. The amount of crop land in partly abandoned farms, which were not included in the 52 farms studied, would also tend to be small and thus tend to raise the proportion of crop land for the 52 farms compared with all farms.

[12] The term "filth" is used locally to refer to sprouts, briers, and weeds which infest the fields.
[13] Long Branch, Old Salem, Pleasant View, Taylor, and Twin Branch.
[14] McGill, Old Union, and Wyan.

TABLE 4.—*Use of land in farms in Laurel County, Ky., and in specified subdivisions, 1924 and 1927*

Use	North area, 1927		Districts 3 and 6, 1924 [3] (census)	South area, 1927		Districts 1 and 2, 1924 [3] (census)	52 farms [1]	8 school districts [2]	Districts 1, 2, 3, and 6 [3] (census)	Laurel County
	30 farms [1]	5 school districts [2]		22 farms [1]	3 school districts [2]					
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Crop land	[4] 47.0	41.2	37.9	[4] 46.5	45.7	40.0	[4] 46.8	43.0	38.6	35.7
Pasture land	26.7	34.6	23.5	13.2	24.9	27.3	21.1	30.7	24.9	19.8
Woodland	19.6	20.4	16.9	32.8	25.6	24.2	25.1	22.5	19.6	29.7
All other [5]	[6] 6.7	3.8	21.7	[6] 7.5	3.8	8.5	[6] 7.0	3.8	16.9	14.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Physical description of crop and pasture fields and detailed data relating to the utilization of crop and pasture lands were obtained from these farms.
[2] Includes all land in farms, whether or not the farms were operated in 1927.
[3] Farms in the north area were located in districts 3 and 6 and farms in the south area in districts 1 and 2.
[4] Orchards and gardens are included under "all other."
[5] Includes farmstead, roads, and miscellaneous waste land. See also footnote 4.
[6] Waste land represents approximately 4.5 per cent of the total for the 30 farms, 4.2 per cent for the 22 farms, and 4.4 per cent for the combined 52 farms. (Table 7.)

On the basis of the general features of the geology and topography of the county and statistics of land use it has been possible to divide the county into four main sectons, the boundaries of which correspond roughly to boundaries of the enumeration districts of the census. This preliminary division of the territory makes possible a more precise definition of the problem. The agricultural potentialities of the western section (districts 4 and 5) are defined practically by what can be accomplished, agriculturally, under conditions prevailing in Laurel County on lands of broken topography, steep slopes, and light soils. The section is agriculturally undeveloped, roads are poor, and the population is sparse compared with other sections of the county. What do the data of the study suggest with regard to the agricultural possibilities of lands of this type?

The northern section presents a somewhat different question. Although a considerable portion of this section (district 3) is rugged, there are extensive areas having the soils and the topographic characteristics associated with the Lee formation. The section is handicapped by lack of roads and yet there is a farm population of 45 persons per square mile. For the northern section the specific questions are: What type of land is best adapted to agriculture? What mistakes, if any, are apparent in the use of this land? What crops and farming practices are best adapted to successful farming on the better lands? What adjustments in the use of land appear desirable?

With regard to the eastern section (district 6), the problems in the use of the land are essentially similar to those of the more rugged parts of the northern section (district 3). Specifically, the problem is to determine the extent to which bottom land and land of fairly moderate slope are essential to successful farming in the section. Corollary to this, is the question as to the amount of land in the section having the essential characteristics.

The central section (districts 1, 2, and 7) presents the anomaly of a large proportion of land in farms and a relatively small amount of farming. A large proportion of the income of farm families in this section is derived from employment off the farm. Is employment

off the farm greater in this section than in others because the land affords a poorer basis for farming, because opportunities for other employment are greater, or do both circumstances combine to furnish the explanation? If because of poor opportunities for farming families in this section must depend on outside employment to obtain an adequate living, what is the outlook for such employment?

In order to obtain from the data of the study at least a tentative answer to these questions, it is necessary to examine the relation of specific land characteristics to the use of land for crops and pasture. This introduces a second step in the analysis.

PHYSICAL CHARACTERISTICS OF CROP AND PASTURE LAND

Detailed physical description of the crop and pasture land was obtained from 52 farms—22 farms in the south area and 30 farms in the north area. On the basis of these data the total area of crop land and pasture land in the 52 farms was classified according to the distinctive physical characteristics or conditions to which the parcel in question most closely conformed. The physical characteristics or conditions definitive of each class of land are shown in Table 5.

TABLE 5.—*Physical characteristics recognized in the classification of crop and pasture land*

Class of land	Slope	Surface	Drainage or erosion	Stones	Stumps
1	Less than 10 per cent.	Smooth to slightly rolling.	Well drained	Typically none [1]	Typically none.
2	do	Smooth to rolling	Typically sheet washing.[2]	Moderate or none	Do.[3]
3	do	do	Heavy erosion	Heavy surface shale.	Do.[4]
4	do	do	Fair to well drained.	Typically none	Stumpy or filthy.[5]
5	5 per cent or less.	Smooth	Poor [6]	do	Typically none.
6	Typically flat	do	do.[7]	do	Do.
7	10 to 20 per cent.	Rolling to rough or hillside.	Heavy erosion	Numerous stones or heavy shale.	Often scattered stumps and filth.
8	20 per cent or more.	Rough or steep hillside.	Erosion typically slight.	Few or none	Typically none.[8]
9	do	Rolling to rough or steep hillside.	Heavy erosion	Typically shale or stones.	Scattered old stumps.[9]
10	do	do	Typically slight erosion.	Typically few or none.	Numerous sound stumps or filth.[10]
11				Rock outcrop; stony land.	

[1] May have light surface shale or few scattered stones.
[2] Occasional gullies; wet spots often at foot of slopes.
[3] May have 1 old, rotten stump per acre.
[4] Weeds and other filth often infest these fields.
[5] Often new clearing with sound stumps combined with old clearing with rotten stumps.
[6] Generally low, with crawfishy or swampy patches.
[7] Predominantly wet, crawfishy, or swampy land.
[8] May have old, rotten stumps; no filth; good stand of grass.
[9] Old clearing; sprouts and other filth not uncommon.
[10] Recent clearing.

The presentation of the physical and economic data relating to the 52 farms is not designed to provide statistical demonstration of the relationships suggested by a comparison of the averages. In many instances the smallness of the sample imparts a very high probable error to the average, but since these averages exhibit a logical and clearly defined pattern, consistent with the pattern suggested by collateral data, it is reasonable to assume that the averages provide

a basis for describing qualitative differences between classes of land, although their use as a basis for accurate quantitative description or comparison may not be justifiable. For example, the figures may convey with all necessary conclusiveness the fact that land in class 1 is economically superior to land in class 3 while leaving a wide margin of doubt that the averages provide an accurate measure of the degree of that superiority.

The 52 farms from which were obtained data descriptive of the physical characteristics of the land comprised 4,643 acres. The percentage of the total acreage falling in each land class is shown in Table 6. Approximately 58 per cent of the farms and of the farm acreage of the 52 farms visited were in the north area. The crop and pasture land is comprised in classes 1 to 11, inclusive. The relatively rugged character of the farms in the north area is shown at once by noting that the crop and pasture acreage comprised in classes 8 to 11, which have slopes of 20 per cent and over, amounts to 46.7 per cent of the total acreage of the 30 farms, whereas the corresponding figure for the south area is 4.8 per cent. (Table 7.) Crop and pasture land in the north area having a slope of 10 per cent and over amounts to more than 50 per cent of the total farm acreage. (Classes 7 to 11.) In the north area, 63.3 per cent of the acreage of crop and pasture land has a slope of 20 per cent or more and 70.4 per cent has a slope of 10 per cent or more. Corresponding figures for the south area are 8 per cent and 29.6 per cent. The 52 farms contained 3,151 acres of crop and pasture land, of which 1,984 acres were in the north area and 1,167 acres were in the south area.

TABLE 6.—*Distribution of crop and pasture land, by classes of land, 52 farms, 1928*

Description	Designated class	Acreage in class	Percentage of total acreage
		Acres	*Per cent*
Smooth to rolling land (slope under 10 per cent):			
In good physical condition	1	364	11.6
In fair physical condition	2	367	11.6
Badly eroded on slopes	3	143	4.5
Stumpy or filthy	4	62	2.0
Total		936	29.7
Land needing drainage (slope 5 per cent or less):			
Generally low with wet spots	5	308	9.8
Predominantly wet or swampy	6	165	5.2
Total		473	15.0
Rolling to rough or hillside (slope 10 to 20 per cent):			
Overcropped and eroded	7	393	12.5
Rolling to rough or steep hillside (slope 20 per cent or more):			
Mostly too rough or steep for plowing	8	357	11.3
Overcropped and heavily eroded	9	875	27.8
Sprout land or new clearing	10	77	2.4
Total		1,309	41.5
Rock outcrop; stony land	11	40	1.3
All classes: total		3,151	100.0

TABLE 7.—*Distribution of all land in farms, by use, and of crop and pasture land, by classes of land, 52 farms, 1928*

Use and class of land	30 farms, north area			22 farms, south area			52 farms, both areas		
	Acreage	Percentage of all land in farms	Percentage of all crop and pasture land	Acreage	Percentage of all land in farms	Percentage of all crop and pasture land	Acreage	Percentage of all land in farms	Percentage of all crop and pasture land
Crop and pasture land in class—	*Acres*	*Per cent*	*Per cent*	*Acres*	*Per cent*	*Per cent*	*Acres*	*Per cent*	*Per cent*
1	136	5.0	6.9	228	11.7	19.5	364	7.8	11.6
2	126	4.7	6.4	241	12.4	20.6	367	7.9	11.6
3	35	1.3	1.8	108	5.5	9.3	143	3.1	4.5
4	37	1.4	1.9	25	1.3	2.1	62	1.3	2.0
5	151	5.6	7.6	157	8.0	13.5	308	6.6	9.8
6	102	3.8	5.1	63	3.2	5.4	165	3.6	5.2
7	141	5.2	7.1	252	12.9	21.6	393	8.5	12.5
8	330	12.3	16.6	27	1.4	2.3	357	7.7	11.3
9	818	30.4	41.2	57	2.9	4.9	875	18.8	27.8
10	70	2.6	3.5	7	.4	.6	77	1.7	2.4
11	38	1.4	1.9	2	.1	.2	40	.9	1.3
Total	1,984	73.7	100.0	1,167	59.8	100.0	3,151	67.9	100.0
Woodland	528	19.6		638	32.7		1,166	25.1	
Farmstead, orchard, and garden	59	2.2		64	3.3		123	2.6	
Roads and waste land	121	4.5		82	4.2		203	4.4	
Total	2,692	100.0		1,951	100.0		4,643	100.0	

UTILIZATION OF LAND FOR CROPS

Crop land comprises 69 per cent and pasture land 31 per cent of the crop and pasture land in the 52 farms. (Tables 8 and 9.) But the proportion used as crop land varies widely between classes, ranging from 12.5 per cent in class 9 to 98.6 per cent in class 1. On the other hand, 50.3 per cent of all the land in pasture is in a single class—class 9. (Table 9.) The physical characteristics of the land undoubtedly affect its use. Conversely, the use of the land for specific crops will certainly affect the physical conditions of the land.

TABLE 8.—*Distribution of crop land, by classes of land, 52 farms, 1928*

Class of land	30 farms, north area			22 farms, south area			52 farms, both areas		
	Acreage of crop land	Percentage of all land in class used as crop land	Percentage of all crop land	Acreage of crop land	Percentage of all land in class used as crop land	Percentage of all crop land	Acreage of crop land	Percentage of all land in class used as crop land	Percentage of all crop land
	Acres	*Per cent*	*Per cent*	*Acres*	*Per cent*	*Per cent*	*Acres*	*Per cent*	*Per cent*
1	136	100.0	10.7	223	97.8	24.5	359	98.6	16.5
2	126	100.0	10.0	235	97.5	25.9	361	98.4	16.6
3	29	82.9	2.3	85	78.7	9.4	114	79.7	5.3
4	15	40.5	1.2	21	84.0	2.3	36	58.1	1.7
5	128	84.8	10.1	84	53.5	9.2	212	68.8	9.8
6	78	76.5	6.2	26	41.3	2.9	104	63.0	4.8
7	107	75.9	8.5	183	72.6	20.1	290	73.8	13.3
8	231	70.0	18.3	12	44.4	1.3	243	68.1	11.2
9	352	43.0	27.8	31	54.4	3.4	383	43.8	17.6
10	59	84.3	4.7	7	100.0	.8	66	85.7	3.0
11	3	7.9	.2	2	100.0	.2	5	12.5	.2
Total	1,264	63.7	100.0	909	77.9	100.0	2,173	69.0	100.0

TABLE 9.—*Distribution of pasture land, by classes of land, 52 farms, 1928*

Class of land	30 farms, north area			22 farms, south area			52 farms, both areas		
	Acreage of pasture land	Percentage of all land in class used as pasture land	Percentage of all land in pasture	Acreage of pasture land	Percentage of all land in class used as pasture land	Percentage of all land in pasture	Acreage of pasture land	Percentage of all land in class used as pasture land	Percentage of all land in pasture
	Acres	*Per cent*	*Per cent*	*Acres*	*Per cent*	*Per cent*	*Acres*	*Per cent*	*Per cent*
1	0	0.0	0.0	5	2.2	1.9	5	1.4	0.5
2	0	0	0	6	2.5	2.3	6	1.6	.6
3	6	17.1	.8	23	21.3	8.9	29	20.3	3.0
4	22	59.5	3.1	4	16.0	1.6	26	41.9	2.7
5	23	15.2	3.2	73	46.5	28.3	96	31.2	9.8
6	24	23.5	3.3	37	58.7	14.3	61	37.0	6.2
7	34	24.1	4.7	69	27.4	26.8	103	26.2	10.5
8	99	30.0	13.8	15	55.6	5.8	114	31.9	11.7
9	466	57.0	64.7	26	45.6	10.1	492	56.2	50.3
10	11	15.7	1.5				11	14.3	1.1
11	35	92.1	4.9				35	87.5	3.6
Total	720	36.3	100.0	258	22.1	100.0	978	31.0	100.0

RELATIONSHIP OF LAND USE TO LAND CHARACTERISTICS

The limitations which physical characteristics place on the use of land for crops and, conversely, the effect of the use of the land or of the kind of crops grown on the physical conditions of the land operate both ways to limit the amount of crop land available. Why is more than 25 per cent of the total corn acreage of the 52 farms grown on the steep, hillside fields of class 9, and only half that proportion on the gently sloping fields of class 1? (Table 10.) Although the acreage of land in class 9 is more than two and one-third times the acreage in class 1, the amount of crop land in the two classes is nearly equal. (Table 8.) Hay has first choice of the class 1 land, as compared with corn. More than 55 per cent of the crop acreage of class 9 land is in corn, whereas over 60 per cent of the crop acreage of class 1 land is in hay. The growing of corn on the steep fields of class 9 is accompanied by rapid erosion and exhaustion of the soil. Hence, fields are rapidly abandoned for crops and become pasture. In the north area, 64.7 per cent of the pasture land is in class 9, and that class comprises 50.3 per cent of all pasture land in the 52 farms.

Thus the amount of crop land, limited in the first instance by physical characteristics, becomes further reduced by conditions arising from the practice of growing crops on land unsuited for that purpose. How is this loss replaced? Historically, it was simply a process of clearing new land. But practically all available land was soon cleared. The characteristic cycle of land use in the mountains then developed. The sequence runs: Clearing, cropping, pasturing, abandonment; reclearing, cropping, etc. To break this vicious circle is the crux of the land-utilization problem in the mountain region.

TABLE 10.—*Acreage in crops and percentage distribution of acreage in crops and of crop acreage, by classes of land, 52 farms, 3-year average, 1926–1928*

ACREAGE IN CROPS

Class of land	Corn	Hay [1]	Oats [2]	Soybeans	Wheat	Tobacco	Miscellaneous	Total
	Acres	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
1	65	215	31	12	22	6	2	353
2	97	131	42	12	28	3	13	326
3	33	33	8	2	1	[3]	3	80
4	6	19	8	----	2	----	[3]	35
5	37	115	15	3	6	----	1	177
6	5	28	3	----	----	----	1	37
7	70	71	32	3	10	1	3	190
8	42	98	35	3	8	1	4	191
9	137	45	52	----	1	1	5	241
10	19	3	7	1	----	----	----	30
Total [4]	511	758	233	36	78	12	32	1,660

PERCENTAGE OF ACREAGE IN CROPS

	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	12.7	28.4	13.3	33.4	28.2	50.0	6.3	21.3
2	19.0	17.3	18.0	33.3	35.9	25.0	40.6	19.6
3	6.5	4.3	3.4	5.6	1.3	[3]	9.4	4.8
4	1.2	2.5	3.4	----	2.6	----	[3]	2.1
5	7.2	15.2	6.5	8.3	7.7	----	3.1	10.7
6	1.0	3.7	1.3	----	----	----	3.1	2.2
7	13.7	9.4	13.8	8.3	12.8	8.3	9.4	11.5
8	8.2	12.9	15.0	8.3	10.2	8.3	12.5	11.5
9	26.8	5.9	22.3	----	1.3	8.4	15.6	14.5
10	3.7	.4	3.0	2.8	----	----	----	1.8
Total [4]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

PERCENTAGE OF CROP ACREAGE

1	18.4	60.9	8.8	3.4	6.2	1.7	0.6	100
2	29.7	40.2	12.9	3.7	8.6	.9	4.0	100
3	41.2	41.2	10.0	2.5	1.3	[3]	3.8	100
4	17.1	54.3	22.9	----	5.7	----	[3]	100
5	20.9	65.0	8.5	1.7	3.4	----	.5	100
6	13.5	75.7	8.1	----	----	----	2.7	100
7	36.8	37.4	16.8	1.6	5.3	.5	1.6	100
8	22.0	51.3	18.3	1.6	4.2	.5	2.1	100
9	56.8	18.7	21.6	----	.4	.4	2.1	100
10	63.4	10.0	23.3	3.3	----	----	----	100
Total [4]	30.8	45.7	14.0	2.2	4.7	.7	1.9	100

[1] Includes millet.
[2] Includes oats for hay as well as for grain.
[3] Less than half an acre.
[4] Class 11 is omitted from this and subsequent tables relating to the utilization of crop land, because the small acreage of crop land in this class was made up of scattered plots on which crops were grown only occasionally and for which no satisfactory figures on production were obtained.

The detailed study of 52 farms in Laurel County furnishes a cross-section view of this cyclical process in the utilization of land. Of the crop and pasture land in the 52 farms, 29.7 per cent has a smooth to rolling surface and a slope under 10 per cent. Land of this description is embraced in classes 1 to 4. (Table 6.) The simplest procedure in exhibiting the relationship of land use to land characteristics on these farms is to discuss the land classes seriatim.

Land placed in class 1 includes 11.6 per cent of the total crop and pasture area. It exhibits physical features and conditions well adapted to the growing of crops. Nearly all (98.6 per cent) the land in this class is crop land. The crop acreage averages over 60 per cent in hay, corn ranking second with 18.4 per cent. Over a 3-year

period 28.4 per cent of the total hay acreage was grown on class 1 land, although land in this class comprises only 16.5 per cent of the crop land. Class 1 land marks the high point, both from the physical and economic standpoint, in the utilization of smooth to rolling land with slopes under 10 per cent.

Class 2 includes practically the same acreage as class 1. The characteristic difference between land in class 1 and that in class 2 is the greater degree of erosion or "sheet washing" and the presence of occasional gullies on class 2 land. In addition, wet spots are found at the foot of the slopes of class 2 land, and scattered stumps occur in the fields. Crop land comprises 98.4 per cent of the acreage in class 2. Hay still predominates in the crop acreage with 40.2 per cent, but the proportion of the crop acreage in corn has increased from 18.4 per cent on the class 1 land to 29.7 per cent on the class 2 land. Nearly 20 per cent of the total acreage of corn is on class 2 land, although this class comprises only 16.6 per cent of the total crop land. Corn tends to be grown on the slopes of class 2 land in part because of better drainage, wet spots often occurring at the foot of the slopes. (Table 5, footnote 2.)

Class 3 includes 4.5 per cent of the total area of crop and pasture land. Class 3 land, essentially like classes 1 and 2 in other respects, is heavily eroded, and the washing out of the soil particles has left a heavy surface coating of shale on the fields. In passing from class 2 to the heavily eroded land of class 3, the most significant fact to note is the increase in the proportion of pasture. Pasture amounts to 20.3 per cent of the acreage in class 3. This pasture use represents, for the most part, a phase of the process of field abandonment and reversion to woodland. Much of the soil is too badly eroded and depleted longer to produce crops. Many of the fields have become infested with weeds and sprouts. (Table 5, footnote 4.) Fields of this description become pasture, and the remaining fields continue to be used principally for the production of hay and corn until the process of deterioration is complete.

The remainder of the area of smooth to rolling land with slopes under 10 per cent is included in class 4. This class comprises only 2 per cent of the acreage of all crop and pasture land in the 52 farms and but 6.6 per cent of the land area in classes 1 to 4, inclusive. In part, this land is made up of old clearings which have been cropped and reverted to pasture without reaching the state of improvement represented by class 1 land. Old clearings often have been extended by the clearing of new land. After cropping to corn for two or three years the land is usually seeded to oats and grass. Hay is cut as long as a stand can be maintained. Stumps interfere with good tillage, and weeds and sprouts quickly recapture the land. The fact that these fields have been incompletely cleared and have been cropped for relatively short periods has checked the progress of erosion.

Land needing drainage comprises 15 per cent of the total area of crop and pasture land in the 52 farms. Land of this description, is embraced in classes 5 and 6. (Table 5.) Land in class 5 is generally low. "Crawfishy" or swampy patches, fit only for grass, restrict the use of the land for cultivated crops. Sixty-five per cent of the crop acreage is in hay. Corn can be grown on some fields at the risk of having part of the crop drowned out. Class 5 comprises 9.8 per cent of the crop and pasture land of the 52 farms. Over 30 per cent of the

land in this class is in pasture. Class 5 includes 15.2 per cent of the total hay acreage on less than 10 per cent of the total crop land. Class 6 includes 5.2 per cent of the crop and pasture land. Land in this class is predominantly wet, "crawfishy," or swampy. Very little of this land can be used for the growing of cultivated crops. Hay averaged 75.7 per cent of the crop acreage over a 3-year period.

Hillside and rolling to rough land with slopes ranging from 10 to 20 per cent (class 7) comprises 12.5 per cent of the crop and pasture area. Although of increasing steepness as compared with land in classes 1 to 6, class 7 land is utilized extensively for the growing of corn. Consequently, the land is heavily eroded and numerous stones and a heavy covering of shale are found in the fields. One-fourth of the land in this class is now used only for pasture of the poorest quality, the use of the field for that purpose merely representing a stage in the process of abandonment. Scattered stumps and filth-infested fields further indicate that the attempt to utilize land of this class chiefly for the production of cultivated crops is likely to prove a failure.

Hillside and rolling to rough land with slopes of 20 per cent or more comprises 41.5 per cent of the crop and pasture area. The surface of much of the land in class 8 is either too rough or too steep to permit the growing of cultivated crops, except on a very limited scale. Class 8 includes 11.3 per cent of the crop and pasture land. Land in class 9 is characteristically more rolling than land in class 8. Its less broken character reduces the difficulty of growing cultivated crops, although the steep slopes erode rapidly under cultivation. The heavy erosion of class 9 land principally differentiates it from land in class 8. The steep, heavily eroded fields of class 9 comprise a larger proportion (27.8 per cent) of the crop and pasture land of the 52 farms than is found in any other class. A small proportion (2.4 per cent) of the crop and pasture area is made up of land of steep or rough topography which has been recently cleared. (Class 10.) Stumps and sprouts usually have not been cleared from the fields. More than 60 per cent of this land was in corn. Rock outcrop and stony land (1.3 per cent) constitutes class 11.

Land of steep slopes in classes 8 and 9 further illustrates tne effect on soil conservation of different cropping practices. Over a 3-year period more than 50 per cent of the crop acreage in class 8 was in grass, whereas in class 9 less than 20 per cent was in grass during the same period. (Table 10.) The fields in class 8 show a good stand of grass and are clean as compared with the fields in class 9, in which sprouts, weeds, and briers abound. More than 55 per cent of crop acreage in class 9, over a 3-year period, was planted to corn. This difference in cropping practice is significant in view of the fact that erosion is typically slight on land of class 8, whereas land in class 9 is heavily eroded.

The relative scarcity of level land and its greater adaptibility to the production of hay, results in the planting of a greater proportion of the crop acreage to corn on lands of intermediate slope (class 7) than on lands of moderate slope. (Classes 1 and 2.) Fields of intermediate slope tend, therefore, to be worn out rapidly. In addition to the tendency to keep them in corn, the rapid erosion of fields in

class 7, due to their steeper slopes, causes them to deteriorate more rapidly than fields in classes 1 and 2. The actual physical difficulty of cultivating fields of more extreme slope in some cases (class 8) has caused these fields to be kept in grass, thus checking erosion. The fact that good stands of grass are maintained on fields of class 8 shows that erosion could be effectively controlled on fields of intermediate slope.

It is proposed now to utilize the classification of land presented here as a basis for studying some economic aspects of the relation of land characteristics to the utilization of crop land.

PERCENTAGE OF CROP LAND IN CROPS

A factor of considerable importance affecting the use of land for crops is the relation of the physical characteristics and conditions of the land to the amount of idle crop land. The proportion of total crop land in crops over a 3-year period ranged from 35.6 per cent for class 6 land to 98.3 per cent for class 1 land. (Table 11.) This ratio of utilization has a direct bearing on the question of a proper measure of the size of farms, and of the efficiency of the farm unit. A farm containing 100 acres of class 1 land will produce more over a given period than a farm containing 50 acres of class 1 land and 50 acres of class 6 land, assuming the same yield per acre on each class, because a very large part of class 6 land lies idle from year to year. To equalize the output on the two classes of land, assuming that idle land in each class is in the proportion shown in Table 11, would require a yield on class 6 land nearly three times as great as the yield on class 1 land. In fact, not only is the ratio of utilization much higher for class 1 than for class 6 land, but also yields obtained from class 1 land are higher. The importance of class 1 land in a farm arises, therefore, not only from the larger yields obtained from it, but also from its higher ratio of utilization as indicated by the proportion of total crop land actually cropped over a 3-year period. The data for extending this comparison to other classes of land appear in Table 11.

TABLE 11.—*Percentage of total crop land in crops, by classes of land, 52 farms, 3-year average, 1926–1928*

Class of land	Acreage of crop land, 1928	Acreage in crops, 1926–1928	Percentage of crop land in crops, 1926–1928	Description of land
	Acres	*Acres*	*Per cent*	
1	359	353	98.3	In good physical condition.
4	36	35	97.2	New clearing.
2	361	326	90.3	In fair physical condition.
5	212	177	83.5	Generally low with wet spots.
10	[1] 66	30	81.1	New clearing.
8	243	191	78.6	Mostly too rough or steep for plowing.
7	290	190	65.5	Overcropped and eroded.
9	383	241	62.9	Do.
3	114	80	70.2	Badly eroded on slopes.
6	104	37	35.6	Predominantly wet or swampy.
Total	[1] 2,168	1,660	77.6	

[1] Twenty-nine acres of land in class 10, not cleared prior to 1926 or 1927, deducted from this figure in computing the percentage of crop land in crops.

CLEARING AND CROPPING SEQUENCE

Thirty-six per cent of the total acreage of crop land in 1928 had been recleared at dates sufficiently recent to be reported by present farm operators for the 52 farms studied. (Table 12.) The proportion of the total acreage reported recleared was highest, naturally, in classes 10 and 4, both because the acreages in these classes are small and because a large part of the land included is new clearing or stump land. It follows that land in these classes has been cropped only a few years since reclearing. The average is 2.9 years for land in class 10 and 11.5 years for land in class 4. Where did the land in these classes appear before it reverted to pasture or brush? Reference to Table 5 will indicate that the rolling to rough or steep hillside land of class 10 is simply a phase of the cycle of utilization of class 9 land. Many of the fields in class 9 are old clearings. Sprouts and other filth are common. Corn occupies 56.8 per cent of the crop acreage. Erosion is heavy. Fifteen years hence the new clearings in class 10 will take the place of the old clearings in class 9.

TABLE 12.—*Average period in 1928 recleared fields had been used as crop land since date last recleared and average acreage recleared annually, 52 farms*

Class of land	Total acreage of crop land, 1928	Acreage in fields for which record of date was obtained		Average period (to 1928) used as crop land since last recleared [1]	Average acreage recleared annually
		Total	Percentage of total acreage of crop land		
	Acres	*Acres*	*Per cent*	*Years*	*Acres*
1	359	77	21.4	23.6	3.3
2	361	136	37.7	18.7	7.3
3	114	28	24.6	16.2	1.7
4	36	30	83.3	11.5	2.6
5	212	46	21.7	30.2	1.5
6	104				
7	290	131	45.2	16.0	8.2
8	243	92	37.9	37.6	2.4
9	383	198	51.7	16.6	11.9
10	66	41	62.1	2.9	14.1
Total or average	2,168	779	35.9	20.6	37.8

[1] Average computed for all fields for which a record of date last recleared was obtained by multiplying the number of years prior to 1928 a field was last recleared by the acreage in that field, and dividing the sum of the products by the sum of the acreages.

Meanwhile, what is happening to this class 9 land? At present 56.2 per cent of it is in pasture. Nearly all this so-called pasture will require cleaning up or reclearing before the land can be cropped. At the rate of reclearing of land in class 10, the shift from class 10 to class 9 would be about 14 acres a year. Over a 15-year period this would add 210 acres of old clearing to class 9, whereas actually 198 acres were reported for an average period of 16.6 years.

The growth of sprouts and other filth on the pasture fields of class 9 tends to check erosion, and these fields are gradually converted into the type found in class 10. The fact that reclearing of this class of land appears to be proceeding at about the same rate as in the past suggests that the four phases of the cycle require about 60 years. Within this longer cycle there is often a shorter one associated with "filth cutting." For example, 20 acres of class 9 land, last cleared in

1928, was reported last previously cleared in 1922 and last cropped in 1924; 10 acres last cleared in 1928 was last previously cleared in 1916 and last cropped in 1919. A crop of sprouts is mowed off or grubbed out and the land is put in corn for two or three years. This process may be repeated a number of times before the field is allowed to revert to pasture.

This cropping sequence is illustrated in Table 13. The practice of cropping to corn two or three years and then pasturing or allowing the land to lie idle was confined largely to fields with steep slopes. This practice was followed on one-sixth of the acreage covered by the records, and three-eighths of the acreage on which the practice was followed was included in classes 9 and 10.

TABLE 13.—*Cropping sequence following clearing of fields, by classes of land, 52 farms*

Class of land	A. Fields for which sequence was corn first year followed by small grain (seeded with grass) second year			B. Fields for which sequence was corn two years followed by small grain (seeded with grass) third year			C. Fields for which sequence was corn two or three years followed by pasture crop or fallow third or fourth year		
	Number of records	Acreage	Percentage of total acreage	Number of records	Acreage	Percentage of total acreage	Number of records	Acreage	Percentage of total acreage
	Number	*Acres*	*Per cent*	*Number*	*Acres*	*Per cent*	*Number*	*Acres*	*Per cent*
1	3	7	3.3	4	16	5.9	0	0	0.0
2	6	36	16.8	10	37	13.8	3	6	6.1
3	1	11	5.1	1	5	1.9	0	0	0
4	0	0	0	3	15	5.6	0	0	0
5	4	28	13.1	1	2	.7	2	4	4.1
6	3	3	1.4	9	8	3.0	2	2	2.0
7	2	6	2.8	9	66	24.5	3	18	18.4
8	3	21	9.8	4	19	7.1	2	31	31.6
9	10	90	42.1	13	78	29.0	5	25	25.5
10	1	12	5.6	4	23	8.5	2	12	12.3
Total	33	214	100.0	58	269	100.0	19	98	100.0

Class of land	D. Fields for which sequence was corn four years followed by small grain (seeded with grass) fifth year			Percentage distribution of acreage				
	Number of records	Acreage	Percentage of total acreage	A	B	C	D	Total
	Number	*Acres*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	0	0	0.0	30.4	69.6	0.0	0.0	100
2	0	0	0	45.6	46.8	7.6	0	100
3	0	0	0	68.8	31.2	0	0	100
4	0	0	0	0	100.0	0	0	100
5	0	0	0	82.3	5.9	11.8	0	100
6	0	0	0	23.1	61.5	15.4	0	100
7	0	0	0	6.7	73.3	20.0	0	100
8	1	3	100.0	28.4	25.7	41.9	4.0	100
9	0	0	0	46.6	40.4	13.0	0	100
10	0	0	0	25.5	49.0	25.5	0	100
Total	1	3	100.0	36.6	46.1	16.8	.5	100

This practice of wearing out and reclaiming land is expensive and wasteful. The process is represented schematically in Figure 5. Some approximation of costs involved in clearing can be made from the data of Table 14. Dynamite is not used, nor are stump pullers employed. A considerable amount of stump land is cultivated, as indicated by land in classes 4, 7, 9, and 10. (Table 5.) In process of time the stumps decay and are chopped out by hand. Man labor is the principal cost involved.

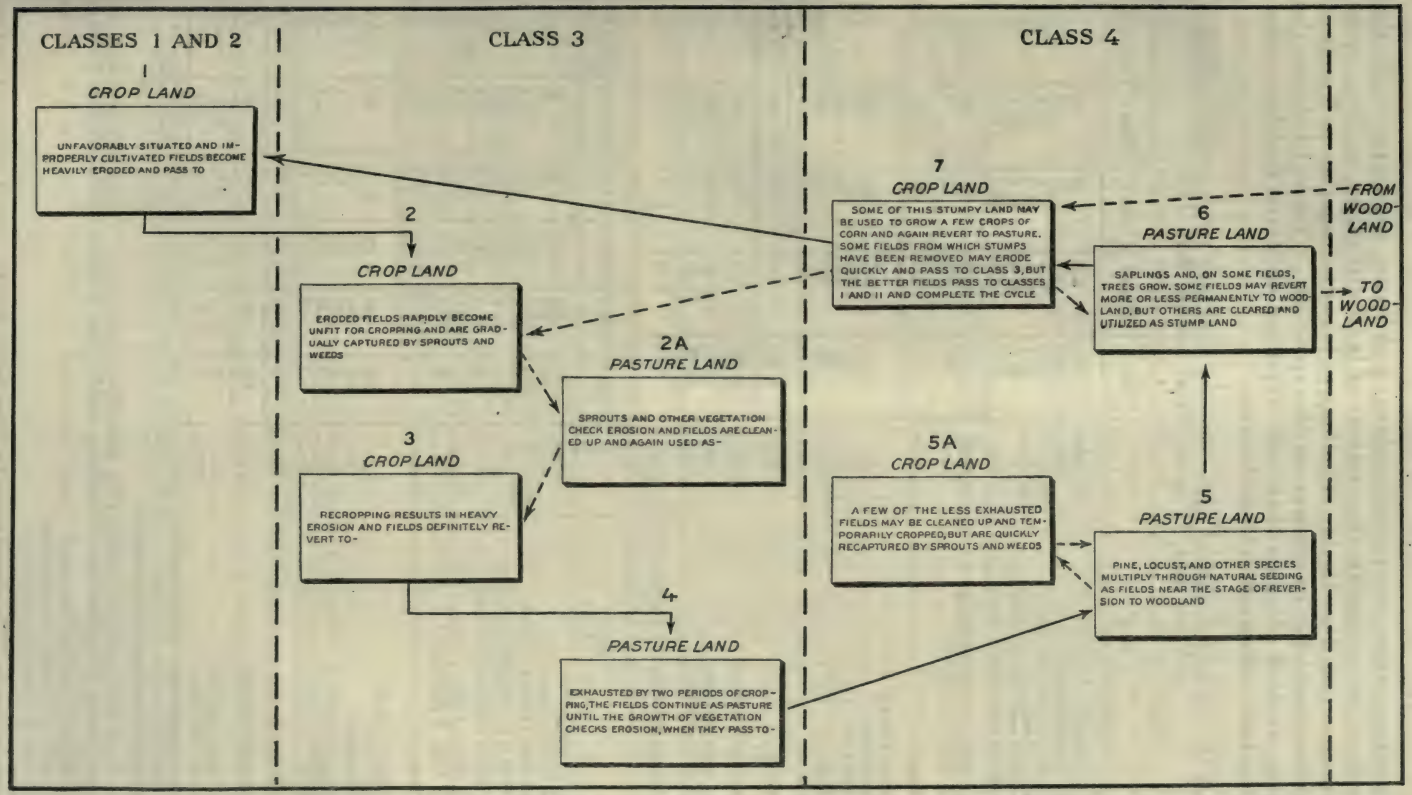
TABLE 14.—*Hours of labor and cost per acre for clearing and breaking land, by classes of land, 52 farms*

Class of land	Records	Acreage	Man labor per acre	Horse work per acre	Cost per acre [1]	Class of land	Records	Acreage	Man labor per acre	Horse work per acre	Cost per acre [1]
	Number	*Acres*	*Hours*	*Hours*	*Dollars*		*Number*	*Acres*	*Hours*	*Hours*	*Dollars*
1	5	42	57.6	11.3	12.65	7	7	63	61.8	10.3	13.39
2	9	72	51.2	66.8	16.92	8	7	63	87.4	11.2	18.60
3	2	6	24.2	19.4	6.78	9	12	158	46.1	21.9	11.41
4	4	36	75.4	25.2	17.60	10	5	41	50.1	20.8	12.10
5	3	14	101.9	26.0	22.98						
6						All classes	[2] 37	495	58.4	[3] 40.5	15.73

[1] In computing money costs, man labor is figured at 20 cents an hour and horse work at 10 cents an hour.
[2] Records were obtained from operators of 37 farms, but when a record covered more than one class of land in a farm that farm was included in each land class covered by the record; hence, the sum of the frequencies is greater than the number of farms.
[3] All classes of land when originally cleared involved horse work. For that reason horse work is included for the entire acreage in computing the horse work involved in clearing all classes of land. The figure, therefore, is not an average of the figures for the several land classes, since these in many cases relate to subsequent stages of clearing operations in which horse work is not involved.

The clearing operations for which man and horse hours were reported were not uniform as to the size of brush or trees removed or as to the completeness of the operation. Consequently, variations in costs more nearly reflect differences in the density or size of the growth removed than differences in land character. However, since the density and size of growth are related to the cycle of land use (fig. 5), the costs are associated also with land character.

It is significant that the labor costs of clearing and breaking reported for class 2 fields closely approximate the costs reported for class 4 fields. (Table 14.) These costs relate, in fact, to the same stage of operations (see stage 6, fig. 5) and are applicable to class 4 land. The clearing costs reported for class 3 apply to the type of operation characteristic of stage 2A, Figure 5. Costs for class 1 and class 2 land logically relate to the type of operations represented by stage 7, Figure 5. The type of operation covered by costs reported for land in classes 5 and 8, include, as a rule, the removal of stumps and are roughly comparable. Operations on classes 9 and 10, on the other hand, are broken into stages—class 9 involving the clearing up of class 10 stump land (see class 1 costs), and the combined cost of the operations on the two classes of land approximate the costs reported for class 5.


CLASSES 1 AND 2
CLASS 3
CLASS 4
1
CROP LAND
UNFAVORABLY SITUATED AND IMPROPERLY CULTIVATED FIELDS BECOME HEAVILY ERODED AND PASS TO
2
CROP LAND
ERODED FIELDS RAPIDLY BECOME UNFIT FOR CROPPING AND ARE GRADUALLY CAPTURED BY SPROUTS AND WEEDS
2A
PASTURE LAND
SPROUTS AND OTHER VEGETATION CHECK EROSION AND FIELDS ARE CLEANED UP AND AGAIN USED AS-
3
CROP LAND
RECROPPING RESULTS IN HEAVY EROSION AND FIELDS DEFINITELY REVERT TO-
4
PASTURE LAND
EXHAUSTED BY TWO PERIODS OF CROPPING, THE FIELDS CONTINUE AS PASTURE UNTIL THE GROWTH OF VEGETATION CHECKS EROSION, WHEN THEY PASS TO-
7
CROP LAND
SOME OF THIS STUMPY LAND MAY BE USED TO GROW A FEW CROPS OF CORN AND AGAIN REVERT TO PASTURE. SOME FIELDS FROM WHICH STUMPS HAVE BEEN REMOVED MAY ERODE QUICKLY AND PASS TO CLASS 3, BUT THE BETTER FIELDS PASS TO CLASSES I AND II AND COMPLETE THE CYCLE
FROM WOODLAND
6
PASTURE LAND
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TO WOODLAND
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CROP LAND
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PASTURE LAND
PINE, LOCUST, AND OTHER SPECIES MULTIPLY THROUGH NATURAL SEEDING AS FIELDS NEAR THE STAGE OF REVERSION TO WOODLAND

FIGURE 5.—SCHEMATIC PLAN OF THE CYCLE OF CLEARING AND CROPPING ON FIELDS OF MODERATE SLOPE

The exact sequence in this cycle in the utilization of fields is subject to variation. The cycle is not characteristic of all fields nor of the farm economy on all farms.

YIELDS, VALUES, AND COSTS, BY CLASSES OF LAND

To what extent do yields, values, and costs associated with the growing of crops justify the method of land utilization and the cycle of land use just described? The figures brought together in Table 15 provide a basis for an answer to this question. Table 12 shows the average number of years that fields reported recleared had been used as crop land subsequent to reclearing.

TABLE 15.—*Estimated annual return obtained from land in crops after deducting specified costs, 52 farms, 3-year average, 1926–1928*

Item	Class 1	Class 2	Class 3	Class 4	Class 5
Acreage in crops—acres	351	213	77	35	176
Acreage in crops grazed—do	207	171	35	16	120
Animal-days [1] grazed per acre—number	39.5	82.0	17.7	22.8	59.4
Percentage of crop acreage seeded—per cent	48.1	70.2	64.0	46.6	46.9
Percentage of crop acreage fertilized—do	29.3	46.0	36.4	33.8	27.2
Percentage of crop acreage limed—do	12.5	16.6	10.6	11.5	6.2
Annual value of crops produced [2]—dollars	6,451	4,598	916	213	1,531
Annual value of pasturage [3]—do	286	491	22	13	249
Total—do	6,737	5,089	938	226	1,780
Total annual cost of—					
Man labor [4]—do	2,331	2,316	339	197	708
Horse work [5]—do	1,000	1,142	162	71	320
Seed—do	223	257	36	16	57
Fertilizer—do	220	255	57	22	186
Lime—do	98	163	8	4	15
Total—do	3,872	4,133	602	310	1,286
Total annual net return—do	2,865	956	336	−84	494
Annual value per acre—do	19.19	16.25	12.18	6.46	10.11
Annual cost per acre—do	11.03	13.20	7.82	8.86	7.31
Annual net return or loss per acre [6]—do	8.16	3.05	4.36	−2.40	2.80

Item	Class 6	Class 7	Class 8	Class 9	Class 10	Total or average
Acreage in crops—acres	36	187	187	236	30	1,628
Acreage in crops grazed—do	36	136	93	159	30	1,003
Animals-days [1] grazed per acre—number	23.3	45.5	58.7	42.3	86.7	52.0
Percentage of crop acreage seeded—per cent	21.2	68.4	64.6	82.4	96.5	62.4
Percentage of crop acreage fertilized—do	22.6	43.2	35.9	40.2	60.6	37.1
Percentage of crop acreage limed—do	2.8	8.4	22.5	7.6	6.2	12.1
Annual value of crops produced [2]—dollars	233	2,055	2,891	2,815	564	22,267
Annual value of pasturage [3]—do	29	217	191	235	91	1,824
Total—do	262	2,272	3,082	3,050	655	24,091
Total annual cost of—						
Man labor [4]—do	256	860	1,238	2,714	193	11,152
Horse work [5]—do	142	393	598	748	57	4,633
Seed—do	9	96	145	105	11	955
Fertilizer—do	13	169	118	167	24	1,231
Lime—do	2	18	116	31	3	458
Total—do	422	1,536	2,215	3,765	288	18,429
Total annual net return—do	−160	736	867	−715	367	5,662
Annual value per acre—do	7.28	12.15	16.48	12.92	21.83	14.80
Annual cost per acre—do	11.72	8.21	11.84	15.95	9.60	11.32
Annual net return or loss per acre [6]—do	−4.44	3.94	4.64	−3.03	12.23	3.48

A minus sign indicates a negative return.

[1] One animal unit grazing on a field for a day constitutes an animal-day. The following were regarded as the equivalent of one animal unit: 1 cow, horse, mule, or steer; 2 calves, yearlings, or colts; 5 hogs; 7 sheep; 10 pigs; and 14 lambs.

[2] Miscellaneous crops not included.

[3] Estimated at 3.5 cents an animal-day.

[4] Estimated at 20 cents a man-hour.

[5] Estimated at 10 cents a horse-hour.

[6] Return obtained from land cropped during the 3-year period, 1926–1928. Cost of clearing and breaking not included.

Assuming that the average annual net return obtained from these fields over the cropping period were identical with the average annual net return obtained from fields in the corresponding land classes (Table 15), it is possible to compute the total net return per acre for cleared fields in each land class over the average period used as crop land. (Table 16). The value of the pasturage on fields reported grazed before and after harvest was included in the gross return from cropped fields. The charge for fertilizer and lime does not apply, of course, to the entire acreage cropped, since only 3 out of every 8 acres were fertilized and only 1 out of every 8 was limed. The figures of Tables 15 and 16 are not designed to show actual costs and returns to be expected from the utilization of various classes of land for crops. They provide, however, a basis for comparing the relative utility of crop land in various classes, under present methods of utilization.

TABLE 16.—*Estimated annual net return per acre obtained from land in crops during the period since last cleared, after deducting cost of clearing and breaking, 52 farms, by classes of land*

Item	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Average
Period used as crop land [1]—year	23.6	18.7	16.2	11.5	30.2		16.0	37.6	16.6	2.9	20.6
Annual net return per acre [2]—dollars	8.16	3.05	4.36	−2.40	2.80	−4.44	3.94	4.64	−3.03	12.23	3.48
Total net return per acre for period used as crop land—do	193	57	71	−28	85		63	174	−50	35	72
Percentage of crop land in crops [3]—per cent	98.3	90.3	70.2	97.2	83.5	35.6	65.5	78.6	62.9	81.1	77.6
Total net return per acre of land in crops—dollars	190	51	50	−27	71		41	137	−31	28	56
Cost of clearing and breaking per acre [4]—do	13	[5] 13	7	18	23		13	19	11	12	16
Total net return per crop acre less cost of clearing and breaking—dollars	177	38	43	−45	48		28	118	−42	16	40
Average annual net return or loss per acre [6]—do	7.50	2.03	2.65	−3.91	1.59		1.75	3.14	−2.53	5.52	1.94

A minus sign indicates a negative return.

[1] Table 12.
[2] Table 15.
[3] Table 11.
[4] Table 14. Since the purpose of the computation of net returns is to provide a basis of comparison between classes of land to illustrate the futility of the practice of wearing out and reclaiming fields, not to measure the comparative advantage of alternative uses of resources, the method employed does not include an interest charge in figuring the costs of improvements and investments.
[5] The type of clearing operation is like that on class 1 land, hence the same cost is used for the 2 classes. (Fig. 5.)
[6] Return from crop land during the average period since last recleared. Cost of clearing and breaking included.

Crop values and costs per acre are given in Table 17. In computing the total net return per acre from cleared fields (Table 16), it is necessary also to allow for the fact that the average annual net return was not obtained each year during the period these fields were cropped, since the data of Table 11 indicate that the acreage of crop land

utilized annually averages less, and often very considerably less than the total acreage of crop land. The total net return per acre was estimated, therefore, to correspond to the ratio of utilization shown in Table 11. The total net return per acre was obtained, it is assumed, at a cost of clearing shown in Table 14. Deducting the cost of clearing gives the estimated average return from an acre over the average period cropped, after principal direct costs (Table 15) and cost of clearing have been deducted. This figure divided by the number of years cropped gives the estimated average annual net return per acre from the utilization of cleared land for crops in the several land classes.

TABLE 17.—*Value per acre of crops produced and of pasturage of cropped fields and cost per acre of producing crops for specified items of cost, 52 farms, 3-year average, 1926–1928*

Class of land	Value per acre of—		Cost per acre of [1]—				
	Crops produced [2]	Pasturage of cropped fields [3]	Man labor	Horse work	Seed	Fertilizer	Lime
	Dollars	*Dollars*	*Hours*	*Hours*	*Dollars*	*Dollars*	*Dollars*
1	18.38	1.38	33.2	28.5	1.32	2.14	2.23
2	14.69	2.87	37.0	36.5	1.17	1.77	3.14
3	11.90	.63	22.0	21.0	.73	2.05	1.02
4	6.09	.81	28.1	20.3	.98	1.86	1.08
5	8.70	2.08	20.1	18.2	.69	3.88	1.38
6	6.47	.82	35.6	39.4	1.18	1.60	1.67
7	10.99	1.59	23.0	21.0	.75	2.09	1.12
8	15.46	2.05	33.1	32.0	1.20	1.76	2.75
9	11.93	1.48	57.5	31.7	.54	1.76	1.74
10	18.80	3.03	32.2	19.0	.38	1.32	1.64
Average	13.68	1.82	34.3	28.5	.94	2.04	2.32

[1] The costs per acre for seed, fertilizer, and lime apply, not to the total acreage in crops (Table 15), but only to the proportion of the total acreage for which the given cost was incurred. The proportions are shown in Table 15. The figures for man labor and horse work apply to the total acreage in crops.
[2] Obtained by dividing the annual value of crops produced by the acreage in crops. (Table 15.)
[3] Obtained by dividing the annual value of pasturage by the acreage in crops grazed. (Table 15.)

Crops grown on class 1 land showed a high average yield and value of product per acre (Table 18) compared with yields and values per acre for other classes of land. The return per acre after deducting principal direct costs amounted to $8.16 for class 1 land. This comparatively high return is due principally to the relatively high crop values per acre (Table 17), since labor costs are considerably lower on certain classes of land from which the return obtained is less. Although the cost per acre of seed, fertilizer, and lime is comparatively high, the percentage of the total acreage fertilized is relatively low. The net return per acre obtained from land in this class over an average period of 23.6 years, after deducting the cost of clearing and breaking, amounted to $7.50 annually. (Table 16.) The relative superiority of class 1 land is reflected by an average reported value of $61 an acre, which is much higher than the average reported value of any other class of land.

TABLE 18.—*Yield and value per acre of crops, by classes of land, 52 farms, 3-year average, 1926–1928*

YIELD PER ACRE

Class of land	Corn	Hay [1]	Oats for hay	Oats for grain	Soybeans	Wheat	Tobacco	Miscellaneous [2]
	Bushels	*Pounds*	*Pounds*	*Bushels*	*Pounds*	*Bushels*	*Pounds*	
1	26.2	1,398	1,011	10.1	2,025	9.6	922	----------
2	22.2	1,134	614	13.3	1,464	5.7	782	----------
3	15.4	689	417	8.9	1,556	4.0	800	----------
4	13.4	784	417	8.8	----------	0	----------	----------
5	15.4	874	174	10.6	2,000	5.9	----------	----------
6	15.4	662	0	0	----------	----------	----------	----------
7	19.3	827	331	8.9	1,467	2.9	686	----------
8	23.8	1,375	1,534	11.8	2,667	11.1	754	----------
9	15.4	622	751	10.2	----------	8.0	575	----------
10	23.4	2,000	----------	8.0	1,600	----------	----------	----------
Average	19.8	1,131	731	10.6	1,801	7.0	825	----------

VALUE PER ACRE

	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
1	26	12	9	7	21	14	222	9
2	22	10	5	7	14	8	182	7
3	15	6	3	5	15	6	144	22
4	13	5	3	4	----------	0	----------	9
5	16	7	1	6	18	9	----------	8
6	15	5	0	0	----------	----------	----------	14
7	19	6	3	5	14	4	128	32
8	24	13	15	6	20	15	146	6
9	15	5	6	7	----------	12	108	12
10	24	15	----------	5	14	----------	----------	----------
Average	20	9	6	6	17	10	189	12

[1] Includes millet.
[2] Includes buckwheat, potatoes, cowpeas, cane, rye, and truck.

On the slightly eroded land of class 2 yields and values per acre are lower than on class 1, and the net return per acre falls to $3.05. This decline is due only in part to lower crop values. The principal factor is higher labor costs. It is an interesting fact that less fertilizer is used per acre, but a much larger proportion of the acreage is fertilized—46 per cent of the class 2 compared to 29.3 per cent of the class 1 acreage. A larger proportion of the class 2 acreage also is limed and at a somewhat higher cost per acre. In spite of these higher costs, incurred in an effort to combat the declining fertility of the soil by more extensive fertilizing and liming and by more intensive cultivation, erosion progresses, and weeds and sprouts tend to recapture the fields. After allowing for cost of clearing and breaking these fields show an annual net return per acre of $2.03 over the average period cropped. This decline in the quality of the land is reflected in a rapid decline in the average reported value per acre of land in this class. The figure for class 2 land is $40 as compared with $61 for class 1 land.

Obviously, some of this class 2 land rapidly reaches the condition descriptive of class 3 land—heavily eroded, weedy, and filth-infested fields. Corn yields decline from 22 to 15 bushels per acre, and hay yields from 1,134 pounds to 689 pounds. These two crops occupy over 80 per cent of the crop acreage of class 3 land. Crop values decline from $14.69 an acre to $11.90 an acre. But in spite of this decline in gross crop values, return per acre, after principal direct costs are deducted, amounts to $4.36 on class 3 land compared with

$3.05 on class 2 land. Seed costs decline principally because the land in class 3 is seldom seeded to hay, as indicated by the decline in the proportion of the crop acreage occupied by oats and the increase in the proportion occupied by hay. (Table 10.)[15] The hay cut is of very poor quality—and the decline in quality is fully reflected neither in the yields nor in the price.

This decline in quality is one factor indicating that the closing phase of a wasteful cycle of land use has arrived. The second is the very marked decline in labor costs. This is not a matter of increased efficiency. On the contrary, it simply represents abandonment by neglect. Over a third of the land lies idle every year. A decreasing proportion of the land is fertilized or limed. The apparent superiority of land in class 3 compared with land in class 2 is of brief duration and appears only at the expense of the land itself. The decline in the quality of the land is accompanied by a decline in the average reported value per acre from $40 for class 2 land to $25 for class 3 land. After allowing for a low ratio of utilization and cost of clearing, class 3 land shows an average annual net return of $2.65 per acre. The fact that this return appears principally through decreased labor costs, associated with neglect of the land and decline in quality of crops, causes the land to pass rapidly into the pasture stage. (Fig. 5, 2A and 4.)

Just as the pasture land of class 4 represents the end of the cycle of land use for land of moderate slope, so also the stumpy or filthy crop land of that class marks the beginning of the cycle. These fields represent a small residuum of land cleared for cropping: (1) Old clearing on which the brush and stumps have never been sufficiently cleared away to permit the fields to pass into classes 1 and 2 or to permit erosion to progress to the point characteristic of fields in class 3; and (2) new clearing on land either too poor or too recently cleared for the stumps to have been removed. This newly cleared land reflects the desperate need for "new" land to replace the worn-out fields of which class 3 land is an example. Except for two or possibly three fair crops of corn, the land does not justify the cost of growing crops, to say nothing of the cost of clearing. The annual loss involved in clearing and using such land does not take account of the deterioration of the soil due to exhaustive cropping and the loss of possible alternative returns to be obtained from the land if devoted to other uses. The unreclaimed land in this class yields even less than class 3 land, on the whole, and crops grown average much less in value per acre. Costs are high relative to class 3 land, so that the returns do not cover the direct costs of growing crops. Operators' estimates of value per acre of this land averaged $17.

Classes 1 to 4 include all the land in the 52 farms having a slope under 10 per cent, except the poorly drained land in classes 5 and 6. With respect to the economy of reclearing land for crops in these four classes, there is no question that the present cycle of utilization is extremely wasteful and ineffective. And yet, the returns obtained from class 1 land indicate that with proper attention to the maintenance and increase of soil fertility through the control of erosion, proper cropping practices, and the economical use of manure, commercial fertilizer, and lime, the land of moderate slope is capable of

[15] Grass crops almost invariably are seeded with oats.

producing a fair return. But obviously that result never can be achieved so long as the present wasteful cycle of land use is permitted to continue.

Fifteen per cent, an unexpectedly large proportion, of the crop land in the 52 farms was found to need artificial drainage. This land is included in classes 5 and 6. For class 5 land the ratio of utilization is low, and nearly two-thirds of class 6 land lies idle annually. Land in these classes is not subject to soil erosion. The land is level and relatively free from stones. If properly drained, therefore, it would have great advantages from the standpoint of cultivation. Drainage and the use of lime would greatly increase the productive capacity of the soil. Under present conditions, the use of class 5 land is largely restricted to the growing of hay, principally redtop, because of poor drainage and the sour condition of the soil. The returns obtained, however, somewhat more than cover the direct costs of producing crops. Class 6 land, on the other hand, is too poorly drained to yield returns which will justify the use of this land for crops. (Table 15.)

Class 7 includes land with slopes intermediate between land in classes 1 to 6 and land in classes 8 to 10. Land in this class, on account of the steeper slopes, erodes rapidly. Recleared fields are cropped for relatively short periods. Of the acreage of crop land in this class 45.2 per cent was reported recleared over a period averaging 16 years. Approximately one-third of the crop land lies idle each year. Sprouts and weeds infest many of the fields. Except for the steeper slopes, class 7 land is similar to class 3 land. Crop values and labor costs per acre for the two classes of land do not differ greatly. (Table 17.) The cropping of the steeper class 7 land produces all the evil effects associated with the use of land of more moderate slope and produces these effects more quickly. One effect of the steeper slopes of class 7 is that the intermediate stage in the deterioration of the land represented by class 2 for land of moderate slope, does not appear. Consequently, the clearing and cropping of class 7 land afford a relatively short interval when the land is in good physical condition. The average period recleared land was reported cropped was 24 years for class 1 land and 19 years for class 2, but only 16 years for classes 3 and 7. The use of class 3 land has the advantage, at least, of a considerable period of cropping (the intermediate stage represented by class 2) before the land deteriorates. The more rapid deterioration of class 7 land makes the use of this land even more uneconomical than the use of the land with moderate slopes. Clearing operations on class 7 land, like those on class 1 land, involve the final stages of cleaning up of fields which have been utilized for crops or of land which has reverted to pasture for relatively short periods. But returns are too low, and reversion is too rapid to justify this clearing and cropping cycle.

The utilization of land in class 8 offers an interesting contrast with utilization of class 7. The slopes of land in class 8 are steeper. Fields in class 8 have been cropped for an average period of 38 years since last recleared, compared with 16 years for class 7 fields. Yet erosion is heavy on fields of class 7 and typically slight on fields of class 8. The superiority of class 8 to class 7 fields is reflected by a higher value per acre, a higher gross per-acre value of crops, a higher yield per acre for all principal crops, more than two and a half times as large a proportion of the acreage limed, a higher ratio of utilization,

and by higher returns per acre. The explanation of this apparent all-round superiority of class 8 land is found principally in the fact that more than half of class 8 land is kept in grass and the fields are managed, in general, to control erosion and to conserve soil fertility. The more moderate slopes of class 7 land tend to encourage the overcropping of these fields.

If class 8 land serves to illustrate what can be done with land of steep slopes, class 9 land is an excellent example of what can not be done. Class 9 land is somewhat less rough than class 8 land, and like class 7 land the fields are somewhat less difficult to cultivate than many fields in class 8. Consequently, over a 3-year period, 57 per cent of the crop acreage of class 9 land was in corn. The extensive growing of corn involves a large amount of hand labor, resulting in relatively high man-labor costs. If anything, class 9 land offers better opportunities for effective utilization than class 8 land, but the difference in method of utilization places all the advantages, so far as results are concerned, with class 8 land. To enumerate: For land in class 9 value per acre is lower, gross value of crops per acre is lower, yields per acre are lower, a much smaller proportion of the acreage is limed, the ratio of utilization is lower, returns per acre are lower.

Most of the land in class 10 is relatively new clearing. Sixty-three per cent of the land is in corn. Yields obtained compare favorably with other classes of land and are much better than yields obtained on the eroded fields of class 9. The land in class 10 was valued at an average of $18 an acre, and the gross value of crops per acre was $18.80, a figure higher than for any other land class. The proportion of the acreage fertilized is practically the same as the acreage in corn, although the quantity of fertilizer used per acre is relatively small. Although the returns obtained from this new land are comparatively good, it is obvious that a few years of cropping to corn will convert these fields into the type found in class 9. That has been and is taking place. At the same time, some of this class 10 land has been developed into land of the type in class 8. There appears, in fact, on land of steep slope in classes 8, 9, and 10, the same cycle of land use, in all essential respects, described for land in classes 2, 3, and 4. The significant difference is that the utilization of class 8 land more closely approaches a sound method, a method designed to give a permanent status to the land, than is true of land either in class 1 or class 2.

The preliminary conclusions relative to the utilization of land for crops may be summarized as follows:

The amount of crop land available is limited chiefly by steep slopes, but approximately 15 per cent of the land is in need of drainage. The practice of cropping the slopes to corn results in rapid erosion, so that fields are quickly worn out. As the land deteriorates it becomes pasture, which, as a rule, is merely a stage of abandonment.

As a consequence of this exhaustive cropping, fields often lie idle. The proportion of the crop land utilized annually decreases as erosion and other types of deterioration of the land progress.

The natural scarcity of land suitable for cropping and the rapid exhaustion of fields by overcropping and consequent heavy erosion, lead to the reclaiming of old fields which have gone back to brush or woodland to replace abandoned crop land.

This clearing and cropping sequence establishes a cycle of land use, the succeeding stages of which are marked by a decline in the physical condition of the land and in the economic returns obtained from it.

Nearly one-fourth of the crop land (classes 4, 6, and 9, Tables 8 and 15) has so deteriorated that the returns obtained are less than the direct costs of growing crops. On an additional 19 per cent (classes 3 and 7) these costs are covered, for short periods, only by "mining" the soil and neglecting the fields.

Conservatively, 4 out of every 10 acres of crop land are losing money, through direct costs and through decline in the value of the land, for the farmer who crops them.

That worth-while returns can be obtained from land in good condition is illustrated, for land of gentle slopes, by class 1 land, and that sound cropping practices are not inconsistent with sound economy is illustrated for land with steep slopes by the fact that on class 8 land where erosion is effectively controlled the returns obtained are positive, whereas on the overcropped and eroded land of class 9 the returns are negative.

UTILIZATION OF LAND FOR PASTURES

Attention has been directed to the fact that a great deal of the land classified as pasture is represented by worn-out fields which have been exhausted by cropping and the progress of erosion. For example, only 1.1 per cent of all land in pasture is represented by the relatively level and slightly eroded fields in classes 1 and 2, although these classes include 23.2 per cent of the crop and pasture land in the 52 farms. On the other hand, 50.3 per cent of the land in pasture is represented by the rough and heavily eroded fields of class 9, although the acreage in this class comprises only 27.8 per cent of the crop and pasture land in the 52 farms.

DESCRIPTION OF LAND IN PASTURES

On the basis of records covering 85.5 per cent of the pasture acreage in the 52 farms, approximately three-fourths of the land in pasture is tillable. (Table 19.) The tendency to use all available bottom land for crops, including hay, is illustrated by the fact that the generally low, crawfishy, or swampy land in class 6 is seldom utilized for pasture if the land can be cropped. Only 20.6 per cent of the pasture land in this class was reported tillable in contrast to much higher percentages in other classes.[16] More than 25 per cent of the pasture land of the rough and eroded fields of class 9 was reported as nontillable, although a part of the acreage, at least, of most pastures in this class was reported tillable. Conditions in class 8, similar to those in class 9, caused about 15 per cent of the acreage to be reported nontillable, and poor drainage placed about 19 per cent of class 5 pasture land in the same status.

[16] Class 11, described as rock outcrop, has very little tillable land.

TABLE 19.—*Percentage of acreage in pasture which farm operator regarded as tillable, by classes of land, 52 farms, 1928*

Class of land	Percentage of acreage for which data were obtained	Percentage of acreage tillable in group—						
		None	1–20	21–40	41–60	61–80	81–100	Average
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	100.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
2	100.0	0	0	0	0	0	100.0	100.0
3	76.7	0	0	0	0	0	100.0	100.0
4	57.4	0	0	0	0	0	100.0	98.6
5	99.0	2.7	0	8.6	0	14.1	74.6	81.4
6	100.0	70.6	0	0	9.0	20.4	0	20.6
7	97.1	0	0	0	0	0	100.0	98.3
8	75.7	9.6	0	0	0	0	90.4	85.6
9	82.3	8.2	1.2	6.1	12.1	25.2	47.2	72.7
10	100.0	0	0	0	0	0	100.0	95.0
11	100.0	94.3	0	0	0	0	5.7	5.7
Average	85.5	13.1	.6	3.9	6.5	15.1	60.8	74.4

Some fields that were reported wholly or in part nontillable may have been cropped to some extent at an earlier period. For example, on the basis of records covering 75.1 per cent of the acreage in the class, only 5.3 per cent of the acreage of the rough and eroded fields of class 9 was reported as previously used for pasture only (Table 20), although more than 25 per cent of the pasture land was reported as nontillable. From 10 to 25 per cent of the land in pasture is now, apparently, regarded by the farmers themselves as unfit for cropping, although all fields now in pasture were probably cleared originally for the purpose of cropping.

TABLE 20.—*Use of pasture fields before conversion to pasture, by classes of land, 52 farms, 1928*

Class of land	Percentage of acreage for which data were obtained	Percentage of acreage in specified use before conversion to pasture					
		Crop land	Crop and pasture land	Pasture land only	Woodland	Idle	Total
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	100.0	0.0	100.0	0.0	0.0	0.0	100
2	100.0	100.0	0	0	0	0	100
3	100.0	100.0	0	0	0	0	100
4	100.0	87.0	0	0	13.0	0	100
5	35.9	89.5	0	3.0	0	7.5	100
6	100.0	11.2	0	88.8	0	0	100
7	97.1	83.0	15.0	0	2.0	0	100
8	71.6	39.0	47.4	13.6	0	0	100
9	75.1	86.2	6.9	5.3	0	1.6	100
10	100.0	100.0	0	0	0	0	100
11	28.6	100.0	0	0	0	0	100
Average	74.7	76.1	12.0	10.0	.7	1.2	100

In general, the less rugged fields (classes 1, 3, and 4) are cleared up at shorter intervals than are the steep or rough fields in classes 7, 8, and 9. On the average, for each field covered by the data a period of 25.8 years elapsed since it was last cleared. The average was 30.1 years for each acre reporting. (Table 21.)

TABLE 21.—*Period since fields utilized as pasture in 1928 were last cleared, by classes of land, 52 farms*

Class of land	Percentage of acreage for which data were obtained	Period since field was last cleared		Class of land	Percentage of acreage for which data were obtained	Period since field was last cleared	
		Average per field	Average per acre			Average per field	Average per acre
	Per cent	*Years*	*Years*		*Per cent*	*Years*	*Years*
1	100.0	8.0	10.7	8	75.9	26.0	27.7
2	0			9	69.3	29.2	34.8
3	93.1	16.3	17.2	10	90.9	[1] 60.0	[1] 76.0
4	69.2	10.2	8.3	11	94.3	24.2	31.8
5	8.9	23.3	19.4				
6	23.8	1.5	1.9	Average	59.2	25.8	30.1
7	34.0	24.2	24.1				

[1] The figure is relatively high because one operator reported a field last cleared 100 years ago.

Farmers agreed that approximately three years was the desirable period to keep a field in pasture. However, fields were reported last seeded 6.7 years ago, on the average, and many fields have been in pasture for much longer periods without reseeding. (Table 22.) Except on class 8 land, which has been protected from erosion, long periods without reseeding indicate, as a rule, that the land is too badly deteriorated to justify reseeding.

TABLE 22.—*Period since fields utilized as pasture in 1928 were last seeded, by classes of land, 52 farms*

Class of land	Percentage of acreage for which data were obtained	Percentage of acreage last seeded within—									Average period since last seeded
		1–3 years	4–6 years	7–9 years	10–12 years	13–15 years	16–18 years	19–21 years	22–24 years	25–27 years	
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Years*
1	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
2	0										
3	100.0	0	23.3	10.0	0	0	66.7	0	0	0	13.2
4	100.0	68.5	13.0	0	0	18.5	0	0	0	0	4.6
5	38.0	19.7	8.5	64.8	7.0	0	0	0	0	0	6.3
6	17.9	62.5	37.5	0	0	0	0	0	0	0	2.8
7	42.7	4.5	70.5	18.2	6.8	0	0	0	0	0	5.6
8	90.3	37.7	40.8	8.1	0	0	0	13.4	0	0	6.1
9	80.6	26.2	44.8	1.8	10.1	8.1	0	0	7.5	1.5	7.2
10	100.0	100.0	0	0	0	0	0	0	0	0	3.0
11	28.6	80.0	20.0	0	0	0	0	0	0	0	3.4
Average	69.3	29.7	40.2	7.4	6.7	5.5	3.0	2.2	4.4	.9	6.7

PREPARATION AND USE OF PASTURES

The meadow and pasture stage in field utilization may be reached after one to four years of cropping to corn. (Table 13.) The general practice has been to crop the land to corn as long as a crop can be obtained and then seed oats and some grass, usually redtop, although timothy, orchard grass, and clover are seeded. After harvesting a

crop of oats,[17] hay will be cut as long as a stand can be maintained, then the field may be pastured or may lie idle from four to six years. At the end of this period sprouts may be cleared off and the field plowed and replanted to corn. This process may be repeated a number of times before the field ceases to be reclaimed from the pasture stage and reverts to woodland. The land usually is plowed, and sometimes harrowed and dragged before the seed is sown by hand; the seed is then harrowed or plowed in.

An average of 8.5 man hours and 14.8 horse hours per acre was reported for plowing and 2.6 man hours and 4.8 horse hours per acre for other operations, or a total of 11.1 man hours and 19.6 horse hours per acre for seed-bed preparation. Labor costs reported for plowing averaged somewhat higher on the wet soils of fields in class 6 than on fields in other classes reporting. (Table 23.) Labor costs of seeding averaged only 2.3 man hours and 4 horse hours per acre.

Since most fields are seeded by hand, there are no significant differences in cost between the various land classes. On the average there are expended on each acre in pasture 5.7 hours of man labor and 3 hours of horse labor annually for filth cutting. (Table 23.) Labor costs of keeping weeds and sprouts under control are relatively high on the partially cleared land in class 4 and on the steep and eroded fields of class 9. A mowing machine is often employed to clear a field of sprouts. But pastures with steep slopes, particularly those which have been neglected (class 9), are usually cleaned up by using a mattock to chop or grub out the sprouts.

TABLE 23.—*Man and horse hours per acre employed on pasture fields for preparing seed bed, seeding, and filth cutting, by classes of land*

Class of land	Seed-bed preparation						Seeding		Filth cutting		Total	
	Plowing		Other operations		Total							
	Man labor	Horse work	Man labor	Horse work	Man labor	Horse work	Man labor	Horse work	Man labor	Horse work	Man labor	Horse work
	Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
1												
2												
3	7.8	15.7	2.6	5.2	10.4	20.9	1.8	3.2	1.4	2.9	13.6	27.0
4	7.2	12.8	2.0	4.0	9.2	16.8	2.3	1.8	6.7	5.7	18.2	24.3
5	10.0	11.4	3.2	4.2	13.2	15.6	3.3	4.6	3.7	4.0	20.2	24.2
6	10.0	20.0	0	0	10.0	20.0	2.0	4.0	2.7	4.2	14.7	28.2
7	6.6	13.2	2.0	4.1	8.6	17.3	2.7	4.7	3.1	3.5	14.4	25.5
8	8.7	17.2	2.7	5.4	11.4	22.6	1.7	4.4	2.6	2.9	15.7	29.9
9	8.6	14.5	2.6	4.8	11.2	19.3	2.5	3.9	7.0	2.5	20.7	25.7
10	0	0	0	0	0	0	0	0	5.0	0	5.0	0
11							3.1	2.5			3.1	2.5
Average	8.5	14.8	2.6	4.8	11.1	19.6	2.3	4.0	5.7	3.0	19.1	26.6

PASTURE COSTS AND RETURNS

For the purpose of evaluating the relative utility of the various classes of land for use as pasture, a typical 6-year period was employed. The land is seeded to oats and hay. An oat crop is harvested

[17] In 1927 the oat crop was practically destroyed by rust.

the first year, followed by two crops of hay. The land is then pastured for three years, during which period allowance is made for the annual cost of filth cutting. Since a varying proportion of the pasture land in the several land classes has been seeded within the last 6-year period (Table 22), costs and returns from oats and hay are included only for the proportion of acreage in each land class which was reported seeded within the 6-year period. For the remaining acreage in each land class returns were estimated only for the pasturage over the 6-year period, and filth cutting was the only cost included for this acreage. Costs of fertilizer were included only for a small proportion of the acreage. The proportion was determined by applying to the acreage seeded in each class of land, the ratio of the acreage of pasture fertilized to the acreage seeded during the period 1926–1928. (Table 24.)

TABLE 24.—*Comparative data relating to the utilization of land for pasture, by classes of land, 52 farms, 1926–1928*

Class of land	Fields for which data were obtained	Acreage in pasture		Value per acre of—			Proportion of acreage fertilized to acreage seeded	Animal units carried per acre	Length of pasture season	Optimum period to pasture field
		Total	Permanent	Seed	Fertilizer	Pasturage [1]				
	Number	*Acres*	*Acres*	*Dollars*	*Dollars*	*Dollars*	*Per cent*	*Number*	*Months*	*Years*
1	1	5	0	-------	-------	2.00	-------	0.50	5.0	0.0
2	1	6	6	-------	-------	2.00	-------	.50	5.0	0
3	2	29	27	0.35	0.43	1.86	46.7	.33	5.7	3.0
4	4	26	4	1.42	1.41	2.76	18.2	.50	5.5	3.0
5	11	96	96	3.02	2.26	1.81	42.4	.35	5.2	3.6
6	6	61	51	1.60	1.44	1.53	100.0	.31	4.9	1.6
7	13	103	91	1.89	1.10	.84	51.4	.19	4.4	3.5
8	8	114	34	1.15	2.49	2.98	13.5	.47	6.4	4.2
9	29	492	292	1.68	1.04	1.83	15.0	.35	5.3	3.2
10	1	11	0	-------	-------	1.20	-------	.20	6.0	4.0
11	3	35	35	-------	-------	.80	-------	.17	4.7	3.0
Total or average	79	978	636	1.49	1.27	1.87	20.6	.34	5.5	3.2

[1] Annual rental value.

Results of the computation appear on an acre basis in Table 25. In arriving at the estimates in Table 25, no account was taken of taxes, interest on investment in land, or the cost of fencing pastures. Taxes and interest on investment would bear little definite relation to the physical characteristics of the land since these charges are based on the value of the farm as a whole. As for the cost of fencing, reports from 52 farms showed for all land classes the following average construction costs per rod: For man labor 0.7 hour, for wire 27 cents, and for posts 20 cents. In computing the value of pasturage the value per acre for pasturage when rented, as estimated by operators, was used. (Table 24.)

TABLE 25.—*Estimated annual net return obtained from pasture land, based on typical 6-year period, by classes of land,*[1] *52 farms*

Item	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Total
Acreage both cropped and pastured ---------- acres	7	18	11	11	33	85	220	385
Acreage pastured only ---------- do	22	8	85	50	70	29	272	536
Total ---------- do	29	26	96	61	103	114	492	921
Value of crops and pasturage on acreage both cropped and pastured:								
Oats, one year ---------- dollars	35	72	66	--------	165	510	1,540	2,388
Hay, two years ---------- do	84	180	154	110	396	2,210	2,200	5,334
Pasturage three years ---------- do	39	149	60	50	83	760	1,208	2,349
Value of pasturage on acreage pastured only:								
Pasturage, six years ---------- dollars	246	132	923	543	353	519	2,987	5,703
Total ---------- do	404	533	1,203	703	997	3,999	7,935	15,774
Annual value per acre ---------- do	2.32	3.42	2.09	1.92	1.61	5.85	2.69	2.85
Cost on acreage both cropped and pastured:								
Seed-bed preparation ---------- dollars	29	63	46	44	114	386	917	1,599
Seed ---------- do	2	26	33	18	62	98	370	609
Fertilizer[2] ---------- do	1	4	11	16	19	29	34	114
Seeding ---------- do	5	12	12	9	33	66	196	333
Harvesting oats ---------- do	12	54	18	--------	54	218	502	858
Harvesting hay, two years ---------- do	43	86	53	53	162	536	1,135	2,068
Filth cutting, three years ---------- do	12	103	38	32	96	207	1,089	1,577
Costs on acreage pastured only:								
Filth cutting, six years ---------- do	75	92	581	288	407	141	2,693	4,277
Total ---------- do	179	440	792	460	947	1,681	6,936	11,435
Annual cost per acre ---------- do	1.03	2.82	1.38	1.26	1.53	2.46	2.35	2.07
Annual net return per acre ---------- do	1.29	.60	.71	.66	.08	3.39	.34	.78

[1] Data relating to land in classes 1, 2, 10, and 11 were not sufficiently comprehensive for the purpose of this table.

[2] Applies only to the proportion of the seeded acreage which was fertilized.

The figures of Table 25 are not designed to show actual costs and returns to be expected from the utilization of various classes of land for pasture. They do reflect, however, the relative utility of land in various classes for pasture under present methods of utilizing these lands. To illustrate, the rough or steep land included in class 8 has no natural advantages to account for the fact that the pastures are superior to those of the rolling-to-rough or steep land of class 9 or to the smooth-to-rolling land of moderate slope in class 3. On the contrary, the physical characteristics of much of class 8 land, in contrast to land in classes 3 and 9, practically prohibit cropping. The result is that a definite effort is made to maintain pastures on class 8 land, thus checking erosion and maintaining fields in a condition generally superior to fields that are overcopped. The general tendency in other classes is to crop fields until they are no longer fit either for crop land or pasture. The results are of the same kind—heavy erosion and exhaustion of soil fertility—whether the land is of moderate slope (class 3) or of steep slope (class 9), although the effects are more rapid and more pronounced on the steep slopes.

CONCLUSIONS RELATIVE TO PASTURES

Two conclusions, one positive and the other negative in regard to the relation of land characteristics to the utilization of land for pasture are suggested by the data. The positive conclusion is that a good

quality of pasturage can be maintained on land too rough or too steep for plowing. (Class 8.) The negative conclusion, borne out by the results shown by every class of land in which fields are subject to overcropping, is that attempts to establish or maintain such fields in pasture either by cultivation, reseeding, or both, without other treatment are hopeless.

The data point also to two conclusions in regard to improving present practices. Preliminary to all other measures, the vicious and wasteful cycle of field utilization characteristic of the farm economy must be eliminated. No sound basis for expenditures for improving pastures can be found until sound practices are followed in the utilization of fields. Pastures can not be established, much less maintained, when rough or steep hillside land (class 9) is allowed to become heavily eroded by overcropping before an attempt is made to convert it into short-term pasture. Seed, labor, and even fertilizer applied under such conditions are almost wholly wasted.

With this preliminary condition met it is clear, in the second place, that yields can be improved and stands of grass maintained only by an adequate application of lime and fertilizer. Recent experiments on methods of pasture improvement, conducted on the livestock and the dairy farms of the West Virginia Agricultural Experiment Station, demonstrate several points which have a direct application to Laurel County farms. The experiments referred to were conducted on lands that were "too steep or rough to make plowing and reseeding practical, but which may be improved by top-dressing with fertilizer and lime" (*10, p. 4*). Some results of these experiments of interest in the present connection follow:

Effect of seeding.—Complex seed mixtures showed no permanent advantage over simple mixtures either in yield or in composition of the pasture. To scatter seed, no matter what the mixture, without applying both lime and fertilizer is a waste of time and effort.

Effect of cultivation.—Liming and fertilizing without cultivation are effective, although a slight increase of yield results from cultivation. Disking without other treatment is futile.

Effect of lime and fertilizer.—Manure, superphosphate, and lime in combination produced the best results. Manure and lime proved the next best treatment. Superphosphate and lime gave marked improvement in yield and quality. Omitting lime reduced the effectiveness in each case. Lime alone gave only small increases in yields, but considerable improvement in quality.

Effect of grazing or mowing.—In the character of vegetation, plots grazed showed little difference from plots mowed.

Costs.—An annual cost of $3 per acre, excluding labor, was involved over a 6-year period in the application of lime, superphosphate, and a seed mixture consisting of timothy, Kentucky bluegrass, alsike clover, and white clover.

Results.—The carrying capacity of pastures, it was estimated, was three times as great as before this treatment was applied, as a result of increased yields and improvement in the quality of the pasture.

The figures of Table 25, particularly those for land in class 8, suggest that a threefold increase in carrying capacity would amply justify an annual expenditure of $3 an acre for lime, superphosphate, and seed on many Laurel County pastures. These West Virginia experiments support the conclusion suggested by the data of the pres-

ent study, particularly by the results obtained from the utilization of the rough or steep land in class 8, that good quality pastures can be maintained on rough or steep land, provided the farm economy is so organized that such lands are not periodically exhausted and subjected to excessive erosion by cropping. But rough land and land with steep slopes are not alone subject to the deteriorating effects of overcropping. The use of lime and fertilizer in combination with a crop rotation to control erosion and soil fertility is also essential on land of more moderate slope, as illustrated by the poor condition both of crop and pasture land in classes 3 and 4. Reference to Table 5 will show that land in class 7 is intermediate in slope between classes 1 to 6 and classes 8 to 10. Land in this class is badly overcropped. The pastures, so called, are virtually worthless, comprising, for the most part, merely exhausted and abandoned crop land.

Detailed suggestions relating to the management of hay and pasture fields are contained in the discussion of the farm management aspects of the study (*9, pp. 252–255*). The data on which these suggestions are based further emphasize the importance of using lime and phosphate and the value of top-dressing with manure to secure good stands of hay and to establish pastures. Control of the growth of filth is also stressed as an important factor in the maintenance of pastures, and it is pointed out that the principal difficulty is encountered during the first year after the land is seeded down to grass.

It was found that some farmers in the area obtain good yields of clover by using as little as 200 pounds per acre of special finely ground limestone, while other farmers using coarsely ground limestone find it necessary to apply from 2 to 3 tons per acre. The use of finely ground limestone should prove especially advantageous to operators of farms located on poor roads.

Successful farmers recommended for pastures the use of lime and phosphate and a seed mixture including red clover, orchard grass, timothy, Lespedeza, and sweetclover. Red clover and timothy appear best adapted to the production of hay, provided the land is limed. Timothy yields a better tonnage than redtop, although redtop does better on wet land and land not limed. Lespedeza is especially valuable when liming is not feasible.

This detailed examination of the relation of land characteristics to the utilization of land for crops and pastures shows the need of examining the farm economy in relation to the land in the farm. Although class 8 land, for example, can be utilized effectively, it can not be utilized effectively as the basis of an entire farm economy. The same statement holds for class 9 land and, at the other extreme, for poorly drained lands in class 5. The definition of agricultural land has, therefore, two aspects. In relation to an area the question is not simply whether the type of land characteristic of the area can be utilized for agriculture, but, further, whether effective utilization of that land depends upon combination with a more or less definite amount of land of a different type. The decision as to the agricultural status of such an area hinges, therefore, on the amount and availability of this additional land. If a sufficient amount of land of the required type is available in an area to justify classing the area as agricultural, it does not follow, of course, that all farms within the area will have the combination of land types essential for successful operation.

From the standpoint of the individual farmer, this second aspect of the problem is the more important. The successful operation of a farm within an agricultural area is contingent upon a proper amount of the favorable type or types of land or combination of such land with less favorable types within the boundaries of the given farm.

The definition of the status of an area provides a basis for a sound policy with respect to the promotion of agriculture, forestry, or other uses of the land. But land characteristics, particularly in an area in which the land is close to the margin of agricultural use, are highly important in relation to the organization of the individual farm. Accordingly, the detailed presentation in this and the preceding section of the relation of land characteristics to the utilization of land for crops and pasture will be turned to account in a subsequent section for two major purposes: (1) To differentiate on the basis of land characteristics, areas which appear to justify agricultural use; and (2) to indicate for the areas so defined the combination of land characteristics within the individual farm that appear to be essential for success. These matters will be presented in the section on farm organization in relation to land characteristics.

UTILIZATION OF WOODLAND

In 1925 woodland in farms amounted to 49,593 acres, or 29.7 per cent, of all land in farms in Laurel County. (Tables 1 and 2.) Woodland comprised 25.1 per cent of the farm area of the 52 Laurel County farms studied by individual fields. (Table 7.) A study was made of the farm wood lots on 49 farms to estimate their significance in the farm economy and their relation to the problem of land use. These 49 farms included 35 of the 52 farms for which records were obtained by individual fields. Thirty-one of the 49 farms were in the south area and 18 were in the north area. The total area of the 49 farms was 4,922 acres. Woodland comprised 1,331 acres, divided into 77 separate tracts, or 27 per cent of the area of the 49 farms. This ratio exceeds by approximately 2 per cent the ratio for the 52 farms and is approximately 3 per cent less than the ratio for the county. (Table 4.)

SLOPE, SURFACE, AND DRAINAGE

Farm wood lots are not confined to the rough or rugged land. The surface of 65.6 per cent of the acreage in woodland in the 49 farms was classed as smooth and an additional 18.2 per cent as rolling. Nor are the wood lots confined to the steep slopes. More than a third of the acreage had a slope of 4 per cent or less and on more than 50 per cent of the acreage slopes ranged under 15 per cent.

The need of land of moderate slope for crops has a tendency, however, to confine farm wood lots to the poorly drained areas for slopes under 5 per cent. Nearly 50 per cent of the woodland acreage with slopes under 5 per cent was reported as only fairly well drained or else wet or swampy. For slopes of 10 per cent and over, comprising 56.6 per cent of the woodland acreage in the 49 farms, poor drainage was practically never a factor.

Relative stoniness of the land was reported for 99.4 per cent of the woodland acreage in the 49 farms. Twenty per cent was described as rock outcrop and surface stones were reported on an additional 41.2 per cent. Except for the considerable porportion of rock outcrop, stoniness as such probably has little to do with the differentiation of

woodland from crop or pasture land in these farms. The hillside lands selected for clearing or cropping are normally those contiguous to the more level land available, while similar land somewhat farther along is allowed to remain in timber. In general, soil depth corresponds to relative stoniness of the land.

PREDOMINANT ORIGIN OF TIMBER

The predominant origin of the timber in the farm wood lots was reported for all except 3 of the 49 farms. For 46 farms, embracing 1,241.5 acres of woodland, the timber on 68.2 per cent of the acreage was predominantly of seedling origin, on 29.8 per cent mixed, and on only 2 per cent predominantly sprout. Approximately 37 per cent of the acreage was reported regularly grazed in 1928. In many instances stock had access to the farm wood lot along with adjacent open pastures, so that no satisfactory estimate of the intensity of grazing was obtained. In some instances stock is turned into the wood lot the year round, but usually from six to nine months is the limit of the pasture season. Reports as to the extent of fencing were obtained from 74 of the 77 tracts. Of those reported, 32 per cent were completely fenced, 57 per cent were partly fenced, and 11 per cent were unfenced. Fencing, however, often consisted only of a strand or two of barbed wire stapled to trees. This type of fence serves to keep cattle and mules out of the cornfields but obviously is no protection against hogs. Consequently, few hogs are turned into the farm wood lots. This is favorable to a large proportion of seedling trees in the stands.

Farm wood lots have suffered very little fire damage in recent years. One or two rumors of fires of incendiary origin for the sake of improving the grazing were heard, but no actual instance was encountered. Only 6 of the 77 tracts reported fires in 1928. These were confined to small areas, so that the extent of the damage was slight. According to the reports of farmers, fires on these 77 tracts have averaged about 1 tract a year during the last 20 years.

COMPOSITION AND VOLUME OF FARM WOOD LOTS

Data on species and volumes obtained from 77 tracts distributed among 49 farms afford a basis for estimating volumes per acre. The estimated total volume of saw timber was 3,109,760 board feet besides 14,531 cords from tops and from trees and species unfit for saw timber. This total gave an average stand per farm of 63,464 board feet and 297 additional cords, and a stand per acre of 2,385 board feet and 11 additional cords. (Table 26.) For the purpose of estimating marketing possibilities as affected by the location of wood lots, the 49 farms were grouped according to the number of trips a day that could be made in hauling timber to the nearest railroad point. These groups were designated, as follows: Group A, 4 trips a day; Group B, 3 trips a day; Group C, 2 trips a day; Group D, 1 trip a day. Table 26 also shows estimated volumes by species separately for these groups. Tracts located close to a railroad point have the largest stand per acre among the several groups, but only a small proportion of the total stand. In fact, only 5 of the 49 farms were located close

enough to a railroad point to admit of four trips a day. Group B (3 trips), included 15 farms; Group C (2 trips), 19 farms; and Group D (1 trip), 10 farms. Tracts on 29, or nearly 60 per cent, of the farms were located so far from a shipping point as seriously to affect the profitable marketing of timber products, particularly in view of the light loads made necessary by poor roads.

TABLE 26.—*Estimated volume of saw timber and cordwood in farm wood lots, by species, 49 farms, 1928*

Species	Group A, 5 farms [1]		Group B, 15 farms [1]		Group C, 19 farms [1]		Group D, 10 farms [1]		Total, 49 farms	
	Saw timber	Cordwood	Saw timber	Cordwood	Saw timber	Cordwood	Saw timber	Cordwood	Saw timber	Cordwood
	Board feet	*Cords*	*Board feet*	*Cords*	*Board feet*	*Cords*	*Board feet*	*Cords*	*Board feet*	*Cords*
Beech	12,583	55	0	72	6,225	22	0	0	18,808	149
Chestnut	0	47	26,332	177	71,429	177	34,459	340	132,220	741
Gum	64,457	256	66,945	404	45,053	153	20,506	93	196,961	906
Hemlock	0	0	34,878	342	0	18	47,540	168	82,418	528
Maple	21,333	250	47,610	781	10,679	235	66,683	128	146,305	1,394
White oak	55,696	177	200,514	1,360	206,022	718	254,529	1,276	716,761	3,531
Other oaks	57,111	195	251,039	1,005	366,761	1,311	182,890	876	857,801	3,387
Poplar	35,685	43	106,593	329	92,830	100	24,092	126	259,200	598
Sourwood	0	42	0	68	0	32	0	64	0	206
Pine	8,415	0	133,368	524	73,353	498	412,798	875	627,934	897
Hickory	6,061	46	12,317	163	8,439	81	11,436	348	38,253	638
Birch	6,609	39	11,314	29	4,848	94	5,467	0	28,238	162
Black walnut	0	0	0	0	4,861	0	0	0	4,861	0
Wahoo	0	0	0	0	0	0	0	106	0	106
Sassafras	0	0	0	0	0	0	0	64	0	64
Ash	0	0	0	42	0	33	0	0	0	75
Dogwood	0	0	0	23	0	24	0	0	0	47
Shadbush	0	0	0	0	0	21	0	0	0	21
Service	0	0	0	81	0	0	0	0	0	81
Total	267,950	1,150	890,910	5,400	890,500	3,517	1,060,400	4,464	3,109,760	14,531
Stand per farm	53,590	230	59,394	360	46,868	185	106,040	446	63,464	297
Stand per acre	2,835	12	1,980	12	2,666	10	2,492	10	2,385	11

[1] Groups are based on the number of trips a day that can be made from the farm wood lot to the nearest railroad point by a team hauling a loaded wagon: Group A, 4 trips a day; Group B, 3 trips a day; Group C, 2 trips a day; Group D, 1 trip a day.

The percentage distribution of volumes by species shows that oaks predominate over all other species combined, accounting for 50.6 per cent of the estimated total volume of saw timber in the 77 tracts. White oak comprised 23 per cent of this volume. (Table 27.) The quality of the white, red, and small chestnut oak in these stands was generally good. This was true also of yellow poplar, pine, and red gum. Among these species, pine alone accounted for any considerable proportion of the total volume. Most of the pine was shortleaf, although a considerable amount of pitch pine was found. Natural seeding of shortleaf pine quickly recaptured abandoned fields. One old-field stand showed a mean annual growth of 400 board feet per acre for 38 years. At the time of the study this stand tallied 16,000 board feet per acre.

TABLE 27.—*Percentage distribution of volume of saw timber and cordwood in farm wood lots, by species, 49 farms, 1928*

Species	Group A, 5 farms		Group B, 15 farms		Group C, 19 farms		Group D, 10 farms		Total, 49 farms	
	Saw timber	Cord-wood	Saw timber	Cord-wood	Saw timber	Cord-wood	Saw timber	Cord-wood	Saw timber	Cord-wood
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Beech	4.7	4.8	0.0	1.3	0.7	0.6	0.0	0.0	0.6	1.0
Chestnut	0	4.1	2.9	3.3	8.0	5.0	3.3	7.6	4.3	5.1
Gum	24.0	22.3	7.5	7.5	5.1	4.4	1.9	2.1	6.3	6.2
Hemlock	0	0	3.9	6.3	0	.5	4.5	3.8	2.7	3.6
Maple	8.0	21.7	5.3	14.5	1.2	6.7	6.3	2.9	4.7	9.6
White oak	20.8	15.4	22.5	25.2	23.1	20.4	24.0	28.6	23.0	24.3
Other oaks	21.3	17.0	28.2	18.6	41.2	37.3	17.2	19.6	27.6	23.3
Poplar	13.3	3.7	12.0	6.1	10.4	2.8	2.3	2.8	8.3	4.1
Sourwood	0	3.6	0	1.3	0	.9	0	1.4	0	1.4
Pine	3.1	0	15.0	9.7	8.2	14.2	38.9	19.6	20.2	13.1
Hickory	2.3	4.0	1.4	3.0	1.0	2.3	1.1	7.8	1.2	4.4
Birch	2.5	3.4	1.3	.5	.5	2.7	0.5	0	.9	1.1
Black walnut	0	0	0	0	.6	0	0	0	.2	0
Wahoo	0	0	0	0	0	0	0	2.4	0	.7
Sassafras	0	0	0	0	0	0	0	1.4	0	.5
Ash	0	0	0	.8	0	.9	0	0	0	.5
Dogwood	0	0	0	.4	0	.7	0	0	0	.3
Shadbush	0	0	0	0	0	.6	0	0	0	.2
Service	0	0	0	1.5	0	0	0	0	0	.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

An interesting feature of Table 27 is the tendency for the proportion of oak and pine in the stands to increase as the distance from the railroad point increases, indicating that variation in distance from market is probably the most significant factor affecting the present composition of stands. The other merchantable species making up these stands were generally inferior in quality. Scarlet oak was very wormy and showed rot, but this condition was less pronounced in swamps. Black oak was somewhat less defective. Chestnut blight was in evidence. As a rule, neither chestnut nor hemlock was of good quality.

Rot and limbiness were the usual defects reported to account for the inferior quality of the stands. Fire scars were reported in only a few instances, although some of the cases of rot reported were doubtless due to fire. None of these stands is fully stocked; hence the land is not being utilized to maximum capacity. One consequence is excessive limbiness and inferior quality of timber. Trees showing rot or other damage and species of inferior value should be culled from these stands to encourage restocking of sound trees of preferred species. Grazing should be controlled to permit full restocking of stands. Density of stands averaged about 0.7, although tracts in group C average 0.8. Limbiness was reported for a considerably smaller proportion of the acreage in this group.

Under present conditions natural reproduction does not appear to be increasing the density of stands. The nine tracts included in Group A showed an average density of 0.8 for the reproduction, but apparently considerable of the young growth was shaded out in the comparatively denser stands in Group C. The average density of reproduction of stands in this group was 0.6. The reproduction was reported as suppressed on a considerable proportion of the acreage falling in Groups B and C. Oak predominates among the species in the reproduction, with 28.5 per cent of the total, of which white oak makes up approximately 12 per cent. Red maple comprises 17.8 per cent of the reproduction, gum 13.3 per cent, of which 9.8 per cent

is black gum and 3.5 per cent is sweetgum. Such comparatively valuable species as pine, poplar, hickory, and chestnut comprise comparatively small proportions of the reproduction. (Table 28.)

TABLE 28.—*Percentage distribution of reproduction, by species, 1928*

Species	Group A, 5 farms	Group B, 15 farms	Group C, 19 farms	Group D, 10 farms	Total, 49 farms
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
White oak	3.9	11.1	8.3	15.4	11.6
Black oak	5.8	7.4	8.0	5.5	6.7
Black and white oak [1]	0	0	.8	0	.2
Scarlet oak	1.6	2.9	7.6	7.4	5.5
Red oak	3.9	4.0	2.6	0	2.2
Chestnut oak	3.9	1.7	4.2	.9	2.1
Post oak	1.0	.3	.1	0	.2
Maple	18.8	18.3	9.6	21.8	17.8
Dogwood	4.5	6.6	8.4	12.6	9.1
Black gum	15.5	9.9	10.4	8.3	9.8
Sweetgum	18.8	5.2	1.7	0	3.5
Sourwood	4.2	9.6	7.9	6.8	7.8
Hickory	3.9	3.5	6.6	3.7	4.2
Chestnut	3.4	1.8	7.7	2.7	3.5
Pine	0	3.2	1.5	4.0	2.9
Sassafras	0	1.2	0	3.1	1.6
Poplar	1.3	2.0	2.5	.2	1.4
Black locust	1.8	.9	1.0	1.0	1.0
Hemlock	0	1.0	0	.6	.5
Shadbush	0	1.2	.1	0	.4
Birch	0	0	1.6	0	.3
Alder	0	.4	.1	0	.2
Miscellaneous [2]	7.7	7.8	9.3	6.0	7.5
Total	100.0	100.0	100.0	100.0	100.0

[1] Not separately recorded.

[2] Miscellaneous species, no one of which comprised more than one-tenth of 1 per cent of the reproduction on the 49 farms, included the following: Holly, magnolia, redbud, hornbeam, shingle, black walnut, ash, witch hazel, red cedar, cherry, and beech.

MARKET CONDITIONS AND STUMPAGE VALUES

The market for lumber in Laurel County is poor. Very little shipping is done, and local demand is slight. Some southern pine is shipped in. Stumpage prices were reported to average about $2.50 per thousand feet at points 10 to 15 miles from a railroad for mixed yellow poplar and white and red (including black and scarlet) oak. Logs have sold for $9 per thousand feet delivered at mill. Log-run yellow poplar lumber is quoted at $25 f. o. b. shipping point.

Ties are in very little demand and grading is strict. For both white oak and red oak the following prices are quoted: No. 5, $1 each; No. 4, 90 cents; No. 3, 70 cents; No. 2, 60 cents; No. 1, 40 cents. Switch ties bring $24 per thousand board feet.

Under present conditions mine timbers afford the best outlet for farm wood-lot products. Generally, all species, except poplar, basswood, and buckeye, are accepted for props, although some companies specify oak and chestnut. Props may be either round or split. The minimum size accepted is 16 square inches at the small end, and the maximum diameter is 10 inches. Lengths desired vary, depending upon the depth of the coal seam, but the range generally is from 5 to 8 feet. Props 6 feet in length would load about 800 to 1,000 in a 40-foot car and 45 props of average diameter would be required for a cord. From 15 to 25 props is a wagon load. Prices paid by local agents of mine companies range from 7 to 18 cents a prop, depending on size. Mine collars are 4 inches minimum diameter at the small end and are from 10 to 14 feet long. Some companies specify that collars must be flat on two sides. Generally, oak and chestnut are the only species accepted for collars. Local prices range from 20 to 60 cents. From 8 to 12 collars is a wagon load.

An abundant local supply of coal reduces the demand for cordwood both for farm use and for sale. In subsequent estimates cordwood is figured at $5 a cord, but the volume of sales is small.

A small quantity of pulpwood is shipped. The principal market, at present, is Kingsport, Tenn. All softwoods are accepted, but no pine or hemlock was reported shipped. Red maple supplies the bulk of the output, but other species included are black gum, sweetgum, and yellow poplar. Wood for pulp is cut in 5-foot lengths and must be peeled, but need not be split. Prices for a cord of 160 cubic feet ranged from $8 to $9, loaded. A small quantity of chestnut extract wood is also shipped at prices ranging about the same as for pulpwood.

Fence posts are in little demand, although a few purchases by farmers in the south area from farmers in the north area have occurred. White oak, post oak, and chestnut fence posts are priced at 15 to 25 cents each. Prices of black locust and red cedar posts range from 40 to 50 cents. Few sales are made at any price.

A few sales of tanbark were reported at $14 a cord (2,200 pounds). The quantities at present available are limited, as most of the chestnut oak trees in the area are small.

This brief summary indicates that the valuations in subsequent tables placed on farm wood lots, under present market conditions, relate more to the potential than to the current value of these stands. Although present markets are not favorable to extensive cuttings from understocked stands, particularly on tracts at a distance from a railroad point, there is an opportunity to cull less valuable trees and species with a view to improving the quality of stands and, except for the more isolated tracts, to cover or better than cover the costs involved in the operation.

The principal factor affecting the stumpage values of these farm wood lots is the distance to a railroad. Hauling costs are especially significant because of very poor roads. However, when farms are grouped by distance to railroad point, there is some difference also in the volume per acre between the different groups. This difference is especially pronounced in the case of Group B farms. On these the farm wood lots averaged 1,980 board feet per acre, whereas Group D farms, the next higher, averaged 2,492 board feet per acre (Table 26), a difference of over 500 board feet per acre.

By utilizing the data of Table 26, stumpage values were computed for farm wood lots in each group of farms. (Table 29.) Wood lots on farms in Group A are relatively accessible. The estimates for wood lots in this group are based on the assumption that a team hauling an average load could make four trips a day to the railroad point. The estimated stumpage value of saw timber for this group is $10.29 an acre, or $3.63 per 1,000 board feet. Tops and trees unfit for saw timber were tallied as cordwood. Cordwood was subdivided into timber fit for mine props and for pulpwood. According to these estimates, each acre of the farm wood lots in Group A contained on the average 2,835 board feet of saw timber, 151 mine props, 7 cords of pulpwood, and 0.5 cord of cordwood. If softwoods fit for mine props were utilized as such, the figure for mine props would be 332, and for pulpwood 0.7 cord. Only trees over 9 inches in diameter at breast height were tallied for saw timber. As pointed out previously, no market for cordwood exists, and the market for mine props and pulpwood is limited. It is probable, therefore, that stumpage values for these stands would average little, if any, over $10.29 an acre.

TABLE 29.—*Estimated value of stumpage of farm wood lots, based on volume per acre in 1928, by types of products, 49 farms*

SAW TIMBER

Group	Acreage [1]	Volume		Market value [2]		Total operating cost at—[3]			Value of stumpage estimated at—[4]					
		Total	Per acre	Total	Per acre	Maximum rate	Minimum rate	Average rate	Maximum cost		Minimum cost		Average cost	
									Total	Per acre	Total	Per acre	Total	Per acre
	Acres	*Board feet*	*Board feet*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
A	94.5	267,950	2,835	5,359	57	3,931	2,725	3,328	338	3.58	1,605	16.98	972	10.29
B	450.0	890,910	1,980	17,818	40	13,560	9,551	11,555	610	1.36	4,819	10.71	2,715	6.03
C	334.0	890,500	2,666	17,810	53	14,542	10,535	12,538	−427	−1.28	3,780	11.32	1,677	5.02
D	425.5	1,060,400	2,492	21,208	50	20,858	16,086	18,472	−4,228	−9.94	783	1.84	−1,723	−4.05
Total or average	1,304.0	3,109,760	2,385	62,195	48	52,891	38,897	45,893	−3,707	−2.84	10,987	8.43	3,641	2.79

CORDWOOD (INCLUDING MINE PROPS AND PULPWOOD)

	Acres	*Cords*	*Cords*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
A	94.5	1,150	12	5,750	61	4,600	3,450	4,025	192	2.03	1,342	14.20	767	8.12
B	458.0	5,400	12	27,000	59	25,218	19,818	22,518	−2,718	−5.93	2,682	5.86	−18	−.04
C	339.0	3,517	10	17,585	52	21,102	17,585	19,344	−6,448	−19.02	−2,931	−8.65	−4,690	−13.83
D	425.5	4,464	10	22,320	52	44,640	40,176	42,408	−26,040	−61.20	−21,576	−50.71	−23,808	−55.95
Total or average	1,317.0	14,531	11	72,655	55	95,560	81,029	88,295	−35,014	−26.59	−20,483	−15.55	−27,749	−21.07

In computing the stumpage value of saw timber, the total overhead cost was estimated at 5 per cent of the total operating cost.
A minus sign indicates a loss.

[1] The figures in this column apply only to the acreage of the given type of product, not to the entire acreage in woodland or in the several groups. The total woodland acreage was distributed as follows: Group A, 99 acres; Group B, 458 acres; Group C, 339 acres; Group D, 435 acres; total 1,331 acres.

[2] The following market prices, f. o. b. shipping point, were used: Lumber, $20 per 1,000 board feet; mine props, 12 cents each; pulpwood, $8 a cord (160 cubic feet); cordwood, $5 a cord.

[3] The following maximum, minimum, and average rates were used: Saw timber, per 1,000 board feet: Felling, $2, $1,50, and $1.75; skidding, $5, $3, and $4; sawing, $6, $4, and $5; pulpwood, per cord, cutting, $2, $1, and $1.50; mine props, per prop, cutting, 3 cents, 2 cents, and 2.5 cents. Hauling was figured at $4 a day for all products. Wagon load: Lumber, 600 board feet; mine props, 20 props; pulpwood and cordwood, 0.5 cord.

[4] Computed by the formula $S=\frac{M}{1+r}-C$, in which S=stumpage value, M=market price, C=operating costs, and r=rate of profit. The rate of profit assumed was 20 per cent.

TABLE 29.—*Estimated value of stumpage of farm wood lots, based on volume per acre in 1928, by types of products, 49 farms*—Continued

CORDWOOD (EXCLUDING MINE PROPS AND PULPWOOD)

Group	Acreage	Volume		Market value		Total operating cost at—			Value of stumpage estimated at—					
									Maximum cost		Minimum cost		Average cost	
		Total	Per acre	Total	Per acre	Maximum rate	Minimum rate	Average rate	Total	Per acre	Total	Per acre	Total	Per acre
	Acres	*Board feet*	*Board feet*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
A	94.5	46	0.5	46	.49	184	138	161	−146	−1.54	−100	−1.06	−123	−1.30
B	458.0	377	.8	377	.82	1,761	1,384	1,572	−1,447	−3.16	−1,070	−2.34	−1,258	−2.75
C	339.0	191	.6	191	.56	1,146	955	1,050	−987	−2.91	−796	−2.35	−891	−2.63
D	425.5	582	1.4	582	1.37	5,820	5,238	5,529	−5,335	−12.54	−4,753	−11.17	−5,044	−11.85
Total or average	1,317.0	1,196	.9	1,196	.91	8,911	7,715	8,312	−7,914	−6.01	−6,718	−5.10	−7,315	−5.55

MINE PROPS

	Acres	*Number*	*Number*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
A	94.5	31,350	332	3,762	40	2,508	2,194	2,351	627	6.63	941	9.96	784	8.30
B	438.5	147,646	337	17,718	40	14,322	12,845	13,583	443	1.01	1,920	4.38	1,182	2.70
C	332.0	91,356	275	10,963	33	11,876	10,963	11,420	−2,740	−8.25	−1,827	−5.50	−2,284	−6.88
D	425.5	133,145	313	15,977	38	30,623	29,292	29,958	−17,309	−40.68	−15,978	−37.55	−16,644	−39.12
Total or average	1,290.5	403,497	313	48,420	38	59,329	55,294	57,312	−18,979	−14.71	−14,944	−11.58	−16,962	−13.14

MINE PROPS (EXCLUDING SOFTWOODS)

A	94.5	14,277	151	1,713	18	1,142	999	1,071	286	3.03	429	4.54	357	3.78
B	438.5	86,911	198	10,429	24	8,430	7,561	7,996	261	.60	1,130	2.58	695	1.58
C	332.0	56,066	169	6,728	20	7,289	6,728	7,008	−1,682	−5.07	−1,121	−3.38	−1,401	−4.22
D	425.5	72,081	169	8,650	20	16,579	15,858	16,218	−9,371	−22.02	−8,650	−20.33	−9,010	−21.18
Total or average	1,290.5	229,335	178	27,520	21	33,440	31,146	32,293	−10,507	−8.14	−8,213	−6.36	−9,360	−7.25

PULPWOOD

	Acres	*Cords*	*Cords*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
A	96.5	645	7	5,160	53	2,580	1,935	2,258	1,720	17.82	2,365	24.51	2,042	21.16
B	452.5	2,699	6	21,592	48	12,604	9,905	11,255	5,389	11.90	8,088	17.87	6,738	14.89
C	339.0	1,074	3	8,592	25	6,444	5,370	5,907	716	2.11	1,790	5.28	1,253	3.70
D	425.5	2,010	5	16,080	38	20,100	18,090	19,095	−6,700	−15.75	−4,690	−11.02	−5,695	−13.38
Total or average	1,313.5	6,428	5	51,424	39	41,728	35,300	38,515	1,125	.86	7,553	5.75	4,338	3.30

PULPWOOD (EXCLUDING SOFTWOODS FIT FOR MINE PROPS)

A	96.5	70	0.7	560	6	280	210	245	187	1.94	257	2.66	222	2.30
B	452.5	288	.6	2,304	5	1,345	1,057	1,201	575	1.27	863	1.91	719	1.59
C	339.0	119	.4	952	3	714	595	654	79	.23	198	.58	139	.41
D	425.5	153	.4	1,224	3	1,530	1,377	1,454	−510	−1.20	−357	−.84	−434	−1.02
Total or average	1,313.5	630	.5	5,040	4	3,869	3,239	3,554	331	.25	961	.73	646	.49

Figures for farms in Groups B, C, and D were computed on the same basis as the figures for farms in Group A. Stumpage values average $6.03 an acre, or $3.05 per 1,000 board feet for stands in Group B, and $5.02 an acre, or $1.88 per 1,000 board feet, for stands in Group C. At present prices, mine props can not be profitably marketed from tracts that permit less than three trips a day. One farmer stated that less than four trips a day was unprofitable for the sale of mine props. Conditions vary, of course, between individual farms.

The farm wood lots in Group D are so distant from a shipping point that only one trip a day could be counted on. The timber stands on those wood lots show a higher volume per acre than the stands on farms in Group B. Yet the excessive cost of hauling so increases the operating costs that average stumpage values are negative. On the assumption of minimum operating costs, stumpage values on these tracts amount only to $1.84 an acre or 74 cents per 1,000 board feet.

For the 49 farms, stumpage values average $2.79 an acre or $1.17 per 1,000 board feet, If full allowance were made for the sale of pulpwood in addition to saw timber, the average value per acre of these stands would amount to $6.09.

PRESENT METHODS OF UTILIZATION]

Most of the farm wood-lot stands are remnants of original growth following partial or selective cutting. Farmers were unable to give a systematic account of cuttings on these tracts, but data were obtained from 42 tracts, which, although incomplete, offer some suggestions as to the type of utilization of farm wood lots and wood-lot products. Minimum diameters of saw timber reported cut from 12 tracts in various years between 1881 and 1910 declined from 18 inches in the first decade to 10 inches in the last decade of the period, indicating a tendency towards heavier culling of these tracts. Nine tracts reported cuttings during the period 1911–1915. Four thousand board feet for home use were reported cut to a minimum diameter of 14 inches from one tract of 15 acres. Pine and oak for lumber and ties were reported cut from five tracts totaling 148 acres. This lumber averaged $15.50 a thousand at the mill. There were 576 ties reported cut from these tracts, of which 476 sold at prices averaging 45 cents, and 100 at prices averaging 88 cents.

Reports covering the last 20 years indicate that an increasing proportion of timber goes into ties, but the volume of sales both for ties and lumber has been small. Small quantities of custom-sawed lumber are also reported cut for farm use. The sale of mine props was not reported for any tract prior to 1926. Reports covering the 3-year period 1926–1928 included five tracts totaling 50 acres, from which 3,050 props were sold at prices averaging 13 cents. Three of these tracts reported minimum diameters as 8 inches, and one reported 10 inches. Posts cut for sale were reported by six tracts for the period 1921–1925 and by three tracts for the period 1926–1928 at prices averaging 18 cents in the earlier period and 20 cents in the later. In most cases reported, small trees were cut for props, but in a few instances 10-inch trees and larger were felled and split. No firewood was reported cut for sale and very little for farm use. Data in

regard to species reported utilized for various products appear in Figure 6.

The fact that comparatively little timber is cut for farm use limited the number of records that could be obtained of labor costs involved in cutting, skidding, and hauling farm-used products of the farm wood lot. Money costs computed from a record of labor hours for cutting timber for farm use are necessarily arbitrary in any event. This work is generally done at a time when opportunities for alternative employment of the farmers' labor are at a minimum. Assuming, however, a rate of 20 cents an hour for man labor and 10 cents an hour for horse work, rates commonly quoted for this type of work, the few records obtained indicate that from 5 to 6 cents a post will cover the cost of cutting and hauling posts for farm use. Cordwood cut for farm use averages $2.90 a cord on the same basis. The

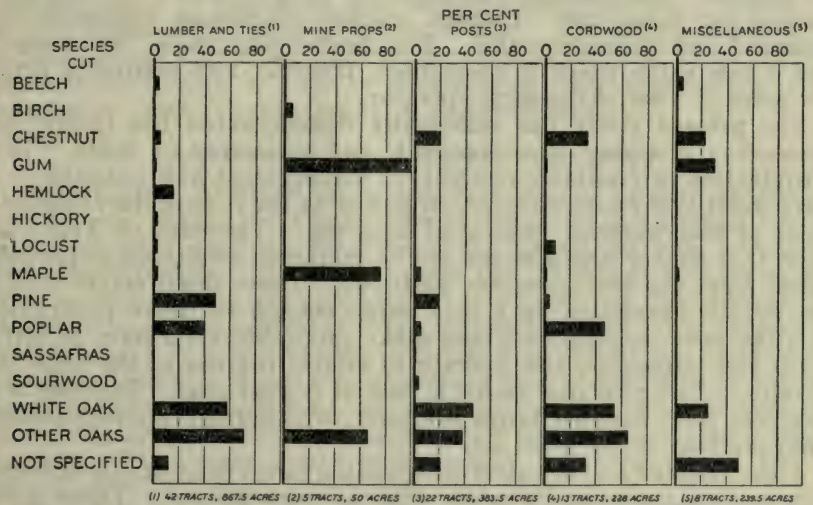

FIGURE 6.—RATIO OF ACREAGE IN TRACTS FROM WHICH A SPECIES WAS CUT FOR SPECIFIED PRODUCTS TO ACREAGE IN ALL TRACTS FROM WHICH THE PRODUCT WAS CUT

Oak, pine, poplar, and hemlock are the species principally cut from farm wood lots for saw timber and ties. Inferior species such as gum, maple, black oak, and scarlet oak go principally into mine props. Rot-resistant species, particularly white oak and post oak, are utilized for posts. Chestnut, gum, and white oak enter into miscellaneous products such as tanbark, extract wood, pulpwood, and staves. Cordwood usually is a by-product of other uses.

records gave a figure of $5.40 a thousand board feet for cutting, skidding, and hauling saw timber for farm use. This appears low when compared with similar figures reported for timber cut for sale, but it is probable that logs cut for farm use can be obtained in sufficient quantity close to the loading point, thus materially reducing the labor of skidding.

These scattered records indicate that farm wood lots have not been utilized to any great extent, if at all, as an established farm enterprise from which a regular income might be derived. So far as the recollection of present farm operators serves as an index of the character and amount of the farm income derived from this source, it would be correct to say that for decades cuttings have been unsystematic and irregular, depending as a rule on the initiative of small sawmill operators who desired to exploit an especially accessible

or valuable tract or on the urgency of the operator's need for ready cash due to special circumstances or conditions. Naturally, the income derived from farm wood lots under these conditions has been neither regular in character nor significant in amount when considered over a period of years.

Instances were reported in which farm operators had more than paid for a tract of land by the sale of the saw timber from a timbered portion of the area purchased. Such instances do not indicate ignorance either of seller or buyer of the potential value of the timber, but in general, markets for timber are so limited and the need for cleared land for crops is so pronounced, that seller and buyer alike are apt to value land in terms of agricultural use. Farmers were often heard to express the view that a hillside already showing a thrifty growth of valuable species 6 to 8 inches in diameter ought to be cleared. The timber was regarded as a liability. It was not needed for home use. Current market conditions suggested no potential and realizable value. But cleared land has a "home use" and a sale value which is immediate, tangible, and realizable from the point of view of the farm operator.

The present study has sufficiently demonstrated the futility of exhaustive cropping, abandonment, and reclearing of fields. The introduction of profitable methods of management and utilization of farm wood lots would do much to justify to the farmer the abandonment of this wasteful process of land use. The data of Table 29 show that timber products can not be marketed profitably at present prices from the less accessible locations. These small tracts would not permit operations on a scale large enough to prove profitable. But the same conditions which make profitable utilization of farm wood lots impossible also operate to inhibit the use of the land for farming. The principal factor is lack of a good road. Markets for products from isolated farms are poor, whether the product comes from the field or the wood lot.

These isolated and so-called self-sufficing farms exist simply because corn and potatoes can be eaten, whereas trees can not. There is no cash market for any crop. The land in these isolated farms is seldom adapted to the growing of cultivated crops. It is forest land. Land of this type and location, if consolidated under private or public ownership into tracts sufficiently large and properly managed, may be economically used to produce timber crops. It is not adapted to the production of corn.

It remains true, nevertheless, that many farms now producing high farm incomes, relative to farms closer to a railroad point, are included among those which can not profitably market farm wood-lot products. For example, farm incomes of farms in Group C average higher than those of farms in Group B. These relatively high farm incomes are usually associated with favorable land characteristics, which offset, in part, the disadvantages of location. Clearly, however, a sound plan of farm organization under conditions confronting farmers in Laurel County must include economical management and utilization of farm wood lots in combination with improved practices in the utilization of land for crops and pasture.

The first consideration in the development of such a plan is to determine the areas in which primary land characteristics are such as to afford a basis for farming. The important problem then is to

determine the methods of land utilization essential to successful farming within these areas. Finally, the conditions corollary to these adjustments such as the extension and improvement of roads, improvements in methods of marketing, etc., must be pointed out. The central thought is the development of efficient farm units, based on the most advantageous use of all the resources of the farm, as the foundation for wholesome family and community life and the maintenance of essential public utilities and services. The data presented in the preceding sections of this bulletin have been designed to provide a basis for these concluding phases of the discussion.

FARM ORGANIZATION IN RELATION TO LAND CHARACTERISTICS

A farm-business analysis of 203 farms[18] shows a wide variation in farm income and in farm organization among these farms. In some respects farms in the south area exhibit characteristics differing in kind or degree from farms in the north area. The present purpose is to relate these differences between farms and between areas to land characteristics with a view to determining their implications and importance from the standpoint of land utilization.

SIZE OF FARMS AND GEOLOGICAL FORMATIONS

Farm income normally bears a direct relation to the number of crop acres in the farm. The number of crop acres in a farm is, therefore, frequently used as a measure of the size of the farm business. But merely to show that an increase in the number of crop acres per farm is attended, on the average, by an increase in farm income of the 203 farms obviously fails to touch certain important questions of farm economy in Laurel County. In the forefront of this problem of the size of farms is the question whether land characteristics permit any significant expansion in the number of crop acres. Where are the relatively small farms as measured by the number of crop acres located? With what land characteristics are these small farms associated?

For the present purpose the factors involved in the location include the area in which the farm is situated, the geological structure from which the soil is principally derived, and the general topographic characteristics and condition of the land. In Table 30 the 83 farms in the south area and the 120 farms in the north area are grouped by number of crop acres, and the percentage of the farms located on each type of geological formation is shown for each crop-acreage group. The fact is at once noted that in the south area the percentage of farms located on the Breathitt formation increases as the number of crop acres increases, whereas in the north area this relationship is inverse. Since in the south area only the Breathitt and Corbin formations are exposed and in the north area only the Breathitt and the Lee formations,[19] it follows that the proportion of farms located on the Corbin conglomerate (south area) decreases as the crop acreage increases, whereas the proportion of farms located on the Lee formation (north area) tends to increase as the number of crop acres increases.

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[18] Details of this phase of the Laurel County study appear in Kentucky Agricultural Experiment Station Bulletin No. 305 (*9*).

[19] The area of the Corbin conglomerate in the north area is too limited to be of significance.

TABLE 30.—*Farms in each crop-acreage group classified by type of geological formation on which the farms were located, 203 farms,[1] 1927*

Size group (crop acres)	Farms	North area				South area		
		Farms	Percentage on Breathitt formation	Percentage on Corbin conglomerate	Percentage on Lee formation	Farms	Percentage on Breathitt formation	Percentage on Corbin conglomerate
	Number	*Number*	*Per cent*	*Per cent*	*Per cent*	*Number*	*Per cent*	*Per cent*
15 or less	40	20	95.0	5.0	0.0	20	55.0	45.0
16–30	86	56	89.3	0	10.7	30	63.3	36.7
31–45	52	31	71.0	3.2	25.8	21	66.7	33.3
Over 45	25	13	61.5	0	38.5	12	75.0	25.0
Total or average	203	120	82.5	1.7	15.8	83	63.9	36.1

[1] Farm-business and family-living summaries are based on records obtained from these farms. The 203 farms include all but 1 of the 52 farms for which detailed data relating to the use of crop and pasture land were obtained.

The importance of these relationships is that soil and topographic characteristics limiting the size of farms are associated with the geological structure on which farms are located. The topographic and soil characteristics of the Corbin conglomerate generally require small farms and the incomes derived directly from the farm are, therefore, usually small. In the north area, the Lee formation, both from the standpoint of soil and topography, is adapted to a larger crop acreage and to the production of a relatively large farm income. The impediments to successful cultivation offered by the Breathitt formation are chiefly topographic. This factor is more pronounced in the north than in the south area, so that a larger proportion of the farms located on the Breathitt formation fall in the larger crop-acreage groups in the south area than in the north area. Table 31 shows the distribution. In the north area only 8.1 per cent of the farms located on the Breathitt formation have over 45 crop acres, whereas 26.3 per cent of the farms located on the Lee formation fall in this class. More than two-thirds of the farms on the Lee formation had over 30 crop acres, whereas two-thirds of the farms on the Corbin conglomerate (south area) had only 30 crop acres or less. Three farms located on the Corbin conglomerate, south area, contained however, 45 crop acres or more (Table 31) and, moreover, the average income obtained from these farms was comparatively high. (Table 32.)

TABLE 31.—*Farms located on each type of geological formation, distributed by crop acreage, 203 farms, 1927*

Area and formation	Farms	Percentage of farms with crop acreage of—				Total
		15 or less	16 to 30	31 to 45	Over 45	
	Number	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
North area:						
Breathitt	99	19.2	50.5	22.2	8.1	100
Corbin	2	50.0	0	50.0	0	100
Lee	19	0	31.6	42.1	26.3	100
South area:						
Breathitt	53	20.8	35.8	26.4	17.0	100
Corbin	30	30.0	36.7	23.3	[1] 10.0	100
Total or average	203	19.7	42.4	25.6	12.3	100

[1] See text, p. 60.

TABLE 32.—*Average farm income by location of farms, geological formation, and crop acreage, 203 farms, 1927*

Location and formation	15 acres or less			16–30 acres			31–45 acres		
	Farms	Farm income [1]		Farms	Farm income [1]		Farms	Farm income [1]	
		Total	Directly from the farm		Total	Directly from the farm		Total	Directly from the farm
North area:	*Number*	*Dollars*	*Dollars*	*Number*	*Dollars*	*Dollars*	*Number*	*Dollars*	*Dollars*
Breathitt	19	149	30	50	257	155	22	331	155
Corbin	1	298	−77				1	−19	−19
Lee				6	410	388	8	466	312
South area:									
Breathitt	11	817	−62	19	288	33	14	332	191
Corbin	9	216	−46	11	164	−12	7	195	−54
Total or average	40	352	−15	86	262	123	52	327	157

Location and formation	Over 45 acres			Total		
	Farms	Farm income [1]		Farms	Farm income [1]	
		Total	Directly from the farm		Total	Directly from the farm
North area:	*Number*	*Dollars*	*Dollars*	*Number*	*Dollars*	*Dollars*
Breathitt	8	564	436	99	277	154
Corbin				2	140	−48
Lee	5	527	480	19	464	380
South area:						
Breathitt	9	558	198	53	455	83
Corbin	3	[2] 543	[2] 459	30	225	15
Total or average	25	552	362	203	332	134

A minus sign indicates a loss.

[1] Obtained by subtracting total farm expenses from total farm receipts. The figure for income obtained directly from the farm was computed by deducting from the total farm income, cash received by the operator for man and team labor and machine work away from the farm, rent of land and buildings, sale of honey, lumber, wood, and similar products. The principal source of such income was from the labor of the operator away from the farm, usually in occupations other than farming.

[2] See text, p. 60.

The acreage in one of these farms included 33 crop acres share rented, leaving only 28 crop acres definitely located on the Corbin conglomerate. A second farm, although located on the Corbin conglomerate, was exceptional in two respects: (1) An unusually large area of level or gently rolling land was available for cropping; and (2) a considerable acreage of truck crops was grown and sold, thus giving a relatively high cash income for the farm. The relatively high farm incomes of these two farms can not be accepted as typical of farms located on the Corbin conglomerate.

Both as to land characteristics and as to farm income, the third farm is more in line with other farms on the Corbin conglomerate. More than two-thirds of the crop land in this farm was rolling to rough or steep hillside, with slopes from 10 to 20 per cent. Fields were heavily eroded and often infested with sprouts and weeds. This farm produced a farm income of $188, which, after deducting income for labor off the farm, was reduced to −$12. On the other two farms, farm income averaged $720. When income from labor off the farm was deducted, the two farms averaged $695.

These relationships suggest, at least as a preliminary conclusion, that farms located on the Lee formation or on the less rugged portions of the Breathitt formation will, as a rule, yield a much better return than farms located on the Corbin conglomerate. If additional facts support this preliminary conclusion, a fair basis will be established for a generalized classification of all the land in Laurel County, so far as its relative agricultural possibilities are concerned.

SIZE OF FARMS AND LAND CHARACTERISTICS

Of the 52 farms studied by individual fields, 51 are included in the group of 203 farms covered by the data of the farm-business analysis. These 51 farms provide a basis for estimating the importance of land characteristics in determining the crop acreage of farms located on each type of geological formation. (Table 33.)

TABLE 33.—*Percentage of crop land in each class of land, by location, geological formation, and crop acreage, 51 farms, 1927*

Location, formation, and size group (crop acres)	Farms	Percentage of crop land in—											Total
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	
North area:	*No.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Breathitt—													
15 or less													
16–30	10	10.0	13.0	9.4	2.6	3.1	3.5	8.3	10.3	37.6	2.2		100
31–45	8	2.2	15.0	.8	2.8	2.4	7.5	14.8	11.2	37.4	5.9		100
Over 45	5	14.1	8.7		.8	1.9	1.5		53.5	13.3	6.2		100
Total	23	8.4	12.4	3.4	2.1	2.5	4.3	8.1	23.9	30.1	4.8		100
Lee—													
15 or less													
16–30	1	34.4					13.5			46.9		5.2	100
31–45	2	.8	6.7			12.3		18.9	11.1	36.8	13.4		100
Over 45	3	28.6	9.7	.6		11.3	1.2	13.4	7.7	14.3	13.2		100
Total	6	21.4	7.3	.3		9.8	2.8	12.9	7.5	26.0	11.2	.8	100
Total	29	11.9	11.0	2.6	1.5	4.5	3.9	9.4	19.5	29.0	6.5	.2	100
South area:													
Breathitt—													
15 or less [1]	1	2.0	49.0	30.6		18.4							100
16–30	4	5.5	14.9	17.4		7.4	1.6	28.9	6.3	14.5	3.5		100
31–45	6	36.0	33.4	1.2		2.1	1.5	24.2		1.6			100
Over 45	5	23.1	22.6	15.9		13.5	5.3	15.4	1.4	2.1	.7		100
Total	16	23.6	26.0	11.5		8.4	3.0	20.5	1.8	4.2	1.0		100
Corbin—													
15 or less													
16–30	3	30.3	31.9	3.2		22.2	10.3			2.1			100
31–45	2	28.7	35.0	26.7	6.4	1.6	1.6						100
Over 45	1	20.8		7.5				67.9		3.8			100
Total	6	27.5	25.5	3.1	9.3	11.5	4.8	16.5		1.8			100
Total	22	24.6	25.9	9.4	2.3	9.2	3.5	19.5	1.3	3.6	.7		100
Both areas:													
15 or less	1	2.0	49.0	30.6		18.4							100
16–30	18	14.6	15.6	9.4	1.3	7.2	5.1	11.0	6.6	26.8	1.9	.5	100
31–45	18	16.3	22.4	.8	4.1	4.0	3.9	17.0	6.2	21.1	4.2		100
Over 45	14	21.1	13.5	6.6	.3	8.2	2.7	13.4	20.2	8.7	5.3		100
Total	51	17.5	17.6	5.6	1.9	6.6	3.7	13.9	11.5	17.7	3.9	.1	100

[1] The single farm included in this group was not operated. The farmer spent 10 months in work off the farm. Consequently, the small crop acreage is not associated with the land characteristics.

In the south area most of the crop land of the Breathitt formation has a slope under 10 per cent. (Classes 1 to 6.) Land in class 7 is of intermediate slope but is heavily eroded and of little use for crops. Class 3 land also, although smooth to rolling, is badly eroded and practically valueless for cropping in its present condition. Farms in the south area located on the Breathitt formation containing over 30 crop acres had a relatively large proportion of crop land in class 1. This is smooth to slightly rolling land. There is little or no erosion, and fields are practically free of stumps and stones.

Farms in the south area located along the Breathitt formation ridges have, as a rule, sufficient land of gentle slope to maintain 30 acres or more in crops. Better cropping practices would easily increase the quantity and improve the quality of available crop land by preventing the loss of fields through erosion, as in classes 3 and 7.

Farms in the south area located on the Corbin formation present a somewhat different picture. Unfortunately, no records of land characteristics were obtained for farms of this group having 15 crop acres or less. From the standpoint of slope and topography, fields on these Corbin formation bottoms are well adapted to cultivation, but this advantage is more than offset by three decisive limitations: (1) Along the margins of the exposed Corbin formation, where the Breathitt formation has been removed, the topography is likely to be precipitous, tending to limit the farm area and to isolate the farm; (2) a considerable portion of the land available for crops requires drainage; and (3) the light, sandy soils derived from the Corbin formation are not, in general, adapted to agriculture.

In the north area a large proportion of the land in farms on the Breathitt formation has steep slopes. A relatively large crop acreage usually necessitates, therefore, the utilization of hillsides with slope of 20 per cent or more. The control of erosion and of filth on these steep slopes is the primary problem in keeping a considerable acreage in crops. On a majority of the farms the operators have not solved this problem, as indicated by the fact that 70 per cent of these farms had 30 crop acres or less. (Table 31.)

The problem centers about the utilization of land of the type in classes 8 and 9. (Table 5.) On farms with more than 45 crop acres nearly three-fourths of the crop land had a slope of 20 per cent and over. (Classes 8 to 10.) But on over 50 per cent of the crop land (Class 8) in farms having more than 45 crop acres erosion is very slight, fields are relatively free of stones, filth has been effectively controlled, and good stands of grass are maintained. As the acreage of crop land decreases there is also a decrease in the proportion of class 8 land and an increase in the proportion of class 9 land—that is, failure to control erosion and filth has resulted in a loss of acreage available for crops.

Nevertheless, the successful utilization of hillside lands is contingent on a combination with land of more moderate slope in the farm acreage. Farms of 16 to 30 crop acres located on the Breathitt formation in the north area have a relatively small crop acreage principally because of failure to control erosion. Land in classes 2 and 3, amounting to more than 20 per cent of the crop land in these farms, illustrates the progress of erosion on fields of gentle slope. Farms in the 31 to 45 crop-acreage group exhibit the same tendency. Fields of intermediate slope (class 7) have been overcropped, as has

been the case, also, with fields of gentle slope until nearly all of this latter type of land has fallen into class 2.

It is possible, therefore, at this point to amplify the picture of the cycle of land utilization previously presented, to include the farm unit. The wasteful methods of utilizing land, previously described, tend slowly to reduce the crop acreage in the farm until its productive capacity is practically destroyed. In terms of family welfare, the result of this process has often been that the son began, not where the father left off, not even where the father began, but actually under a greater handicap through the progressive "mining" to which the land had been subjected.

The limitations imposed on farms located on the Breathitt formation by the necessity of utilizing steep slopes for crop land is less significant for farms located on the Lee formation. Farms located along the Lee formation bottoms have the double advantage of superior soils and of favorable topography. Less than one-third of the crop land of farms on the Breathitt formation has a slope under 10 per cent, whereas in farms on the Lee formation the proportion is over one-half. Moreover, poorly drained land in classes 5 and 6 is of special significance in the case of farms on the Lee formation bottoms. This land produces good yields of hay and is much valued by farmers. Among farms of this group the tendency is for the crop acreage to decline as the proportion of hillside crop land in the farm increases. Of course, the problem of controlling erosion and filth is much simpler with a relatively small proportion of hillside land in crops. Under these conditions, therefore, it is much easier to maintain a relatively large crop acreage.

Taking the several crop-acreage groups without regard to the location of farms, the figures indicate a pronounced tendency for the proportion of the poorly conditioned and heavily eroded hillside crop land (class 9) to decline as the crop acreage per farm increases. Conversely, there is a much larger proportion of the well-conditioned hillside land (class 8) in farms with 45 crop acres and over than in farms with smaller crop acreages. The proportion of class 1 crop land also tends to increase with an increase in the crop acreage.

In general, the situation in the south area may be summarized as follows: (1) Farms on the Breathitt formation must utilize a considerable amount of land of intermediate slope (class 7) as crop land; the rapid erosion of these fields introduces a serious difficulty in maintaining an adequate crop acreage; this problem of erosion control is simplified when a considerable acreage of level or gently rolling land (classes 1 to 6) is embraced by the farm, and if such land is not available the crop acreage must (as a rule) necessarily be small; but even with such land many fields are overcropped (class 2 and especially class 3 land) thus reducing the quantity and quality of the crop land available; (2) farms on the Corbin conglomerate have the double handicap of poor soil and poor drainage; the extent of crop land available is usually small.

In the north area, (1) farms on the Breathitt formation must, as a rule, control erosion and filth on steep, hillside fields in order to maintain an adequate crop acreage; to accomplish this a considerable proportion of ridge land of gentle slope must be included in the farm acreage; (2) farms on the Lee formation are able to maintain relatively large crop acreages, although better control of erosion on the hillsides,

and ditch or tile drainage of the bottoms are greatly needed on these farms.

SIZE OF FARMS AND LAND CHARACTERISTICS IN RELATION TO FARM INCOME

Forty farms having 15 crop acres or less had an average farm income of $352 per farm; 86 farms with 16 to 30 crop acres averaged only $262 per farm, and 52 farms with 31 to 45 crop acres averaged $327—an amount less in each case than that averaged by farms in the lowest crop-acreage group. (Table 32.) But when there is deducted from the net farm income the income derived from other sources,[20] the essential fact appears that the larger the crop acreage the nearer the farm as such comes to returning a living to the operator.

Table 32 shows that work off the farm accounts for a much larger proportion of the income of operators in the south area than in the north area. The question is whether this difference is due to easier access to sources of outside work in London and Corbin from farms in the south area or to poorer opportunities for successful farming in the south area. Topographically, farms in the south area are better adapted to farming than are those in the north area. On the other hand, small incomes derived from farms on the Corbin conglomerate in the south area appear to be due to relative deficiency of the land compared with land on the ridges and moderate slopes of the Breathitt formation and with the land of the Lee formation bottoms.

In general, it appears to be true that farms with less than 45 acres of land suitable for crops, except those located on the Lee formation, whether in the south or the north area, must rely on work off the farm for a considerable portion of the farm income. Incomes earned in the south area indicate that a small crop acreage combined with earnings off the farm as a principal source of income gives a better total net return than a somewhat larger crop acreage with a smaller proportion of the income from work off the farm.

Land characteristics are the principal factor limiting the crop acreage. When the available crop acreage is thus limited, work off the farm is essential to obtain an income adequate for the elementary needs of living. The combination of soil deficiency and unfavorable topography undoubtedly would eliminate a considerable number of the farms in both areas as submarginal even under favorable conditions of farm organization and management.[21]

Some operators now maintaining a fairly large crop acreage, much of it on steep, heavily eroded, overcropped land, would do better to spend all or a major part of their time in other employment, utilizing the farm principally as a residence and garden. Some farms with small acreages but favorable land characteristics would justify an expansion of the crop acreage sufficiently to employ all or a major part of the time of the operator. To obtain an adequate income from the farm, it is apparently essential to have at least 30 to 50 acres of crop land. The smaller the acreage, the greater the proportion of it that must be of gentle slope, relatively free from erosion, and in good tilth (class 1) or land not too wet to produce good crops of hay and

[20] Table 32, footnote 1.

[21] The average net farm income of 90 farm operators who depended mainly upon farming for a livelihood was $319 (*9, p. 234*). Dependence on the farm as the principal source of income is not, however, necessarily confined to farms having favorable land characteristics. Neither is a large crop acreage always directly associated with favorable land characteristics.

fair crops of corn (class 5). Drainage would increase the amount and improve the quality of available crop land on many farms. The inclusion of heavily eroded and poorly conditioned land of gentle slope (class 3) or of intermediate slope (class 7) in itself suggests either unsound cropping practices or an inadequate amount of level or gently rolling land. In the former case, there is no substitute for the introduction of a good rotation, based on a proper selection of crops and the use of fertilizer, to conserve and build up the soil as a means of obtaining an adequate income from the farm. In the latter case, except for possible use as a residence and garden site, the land is definitely submarginal for farming.

No exact line exists for classifying a given farm as above or below the margin of profitable farming, but definite criteria can be applied. Less than 30 crop acres are not likely to yield adequate income under the type of farming suitable for Laurel County. In view of the limited amount of available crop land, if less than 30 per cent of it is of the type falling in classes 1 or 5, or in these two classes combined, if the land with slopes of 20 per cent and over comprised in the crop acreage is not of the type falling in class 8, the farm may rather safely be regarded as submarginal.

It is true that some farms classed as submarginal might be reclaimed by restoring the fertility and conserving the soil of slightly eroded fields (class 2), by redeeming heavily eroded and filth-infested fields (class 3), by establishing permanent pastures on eroded hillsides (class 9), and by draining and utilizing available stretches of bottom land (class 6). Most land in Laurel County that is worth farming can be effectively utilized for that purpose by the relatively simple expedients of properly combining enterprises, using limestone and phosphates, draining wet fields, protecting hillsides from erosion by keeping them in grass and rotating crops.[22]

In addition to the criteria mentioned, it should be added that the soils of the Corbin conglomerate because of their light, sandy character and deficiency of organic matter impose a special difficulty in the successful operation of farms located on this formation. This relative deficiency was reflected to some degree in the average yields of corn obtained from farms located on the Corbin conglomerate compared with average yields obtained from farms located on other formations. For farms in the south area, the average yield on the Corbin formation was 19 bushels, as compared with 21.6 bushels on the Breathitt formation. Farms on the Lee formation in the north area had an average yield of 20.4 bushels, but yields on the steep Breathitt formation slopes in the north area averaged only 19.2 bushels. On the basis of slope and stoniness farms on the Corbin conglomerate compare rather favorably with farms in other locations, although on these farms, as is also true of farms on the Lee formation, poorly drained land usually comprises a considerable proportion of the crop acreage.

VALUE OF CROP LAND IN RELATION TO LAND CHARACTERISTICS

On each of the 52 farms studied in detail an attempt was made to obtain the operator's estimate of the value of individual fields. The aim was to test whether the operators' valuations would bear any relation to the physical descriptions of corresponding fields and to the

[22] The matter of farm budgets is discussed in Kentucky Experiment Station Bulletin 305 (*9*).

yields obtained from them. Notwithstanding an obvious tendency of operators to value all crop land in the farm at the same price per acre, the wide range in the utility of fields was recognized by operators and is reflected to some extent in the estimated values per acre.

The estimates obtained for fields in each land class were grouped according to the geological formation on which the farm was located and then averaged. The results appear in Table 34. Average values conform, in general, to the relative utility of fields as reflected by the physical description of land in the several classes. Average values of class 1 land are highest no matter on what formation the farm is located. The scarcity of level or bottom land is reflected in high average values for land in classes 5 and 6. From the standpoint of its productive capacity, this type of land is overvalued, particularly so in the case of land in class 6. Crop land in farms in the south area tends to be valued at a higher figure than is land of similar characteristics in the north area. This indicates an effect of proximity to London and to the State highway. The relatively high productive capacity of the Lee formation bottoms is reflected in a high reported value of class 1 land for farms located on the Lee formation.

TABLE 34.—*Average value per acre of crop land, based on operators' estimates, by geological formations and classes of land, 52 farms, 1928*

Class of land	Value per acre, north area			Value per acre, south area			Average
	Breathitt formation	Lee formation	Average	Breathitt formation	Corbin formation	Average	
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
1	45	83	64	61	57	60	61
2	26	28	26	53	39	49	40
3	17	15	17	28	25	28	25
4	14	----	14	----	20	20	17
5	16	13	13	31	38	33	20
6	19	19	19	62	37	48	25
7	18	18	18	18	18	18	18
8	27	9	25	12	----	12	24
9	12	9	11	14	15	14	11
10	23	16	18	16	----	16	18
Average	25	22	23	39	38	39	29

SOURCES AND VALUE OF THE FAMILY LIVING IN RELATION TO LAND CHARACTERISTICS

VALUE OF FAMILY LIVING

Family living data were also summarized for the 83 farms located in the south area and the 120 farms located in the north area for which the farm-business data were obtained. The total value of the family consumption of goods, including value of products furnished by the farm, was less than $900 for 165, or 81.3 per cent, of these families. Only four families, or 2 per cent, consumed goods valued at $1,500 or more. The range in the value of the family living for all families was from $214 to $1,946. The proportion of families consuming goods valued at $900 and over was much greater in the south area than in the north area, amounting to 30.1 per cent in the former and to 10.8 per cent in the latter. (Table 35.)

TABLE 35.—*Number and percentage of families in each cost-of-living group, by areas, 203 families, 1927*

Cost-of-living group	North area		South area		Both areas	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
Less than $600	61	50.9	30	36.2	91	44.8
$600–$899	46	38.3	28	33.7	74	36.5
$900–$1,199	10	8.3	16	19.3	26	12.8
$1,200 and over [1]	3	2.5	9	10.8	12	5.9
Total	120	100.0	83	100.0	203	100.0

[1] Includes four families over $1,500.

SOURCES OF INCOME

The relatively higher value of the family consumption of goods by families residing in the south area than by families residing in the north area should be considered in relation to the difference in the sources of income of operators in the two localities. Only one-third of the farm operators in the south area depend mainly on farming for a living, in contrast to one-half of the operators in the north area. (Group A, Table 36.) In the north area, also, a larger proportion of the operators derived their incomes principally from their own labor than was the case in the south area.

TABLE 36.—*Location and size of farms in relation to sources and value of the family living, 203 farms, 1927*

Area, formation, and size group (crop acres)	Farms	Percentage distribution of farms in [1]—				Total value of goods consumed	Income directly from the farm [2]	Farm income [2]
		Group A	Group B	Group C	Total			
	Number	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Dollars*	*Dollars*	*Dollars*
North area	120	51.7	18.3	30.0	100.0	609	186	305
South area	83	33.7	22.9	43.4	100.0	805	58	372
North area:								
Breathitt—								
15 or less	19	26.3	21.1	52.6	100.0	446	30	149
16–30	50	50.0	20.0	30.0	100.0	576	155	257
31–45	22	63.7	13.6	22.7	100.0	667	155	331
Over 45	8	50.0	12.5	37.5	100.0	935	436	564
Total	99	48.5	18.2	33.3	100.0	600	154	277
Corbin—								
15 or less	1			100.0	100.0	616	−77	298
16–30								
31–45	1		100.0		100.0	519	−19	−19
Over 45								
Total	2		50.0	50.0	100.0	568	−48	140
Lee—								
15 or less								
16–30	6	100.0			100.0	562	388	410
31–45	8	50.0	25.0	25.0	100.0	611	312	466
Over 45	5	80.0	20.0		100.0	861	480	527
Total	19	73.7	15.8	10.5	100.0	661	380	464

A minus sign indicates a loss.

[1] The classification here used is that developed in Kentucky Agricultural Experiment Station Bulletin No. 305 (9). Group A includes operators who depended mainly upon farming for a livelihood; Group B, operators whose chief sources of income were contributions of relatives, pensions, interest, and other sources not entailing labor on their part; Group C, operators who derived the greater part of their income from work away from the farm.

[2] See Table 32, footnote 1.

TABLE 36.—*Location and size of forms in relation to sources and value of the family living, 203 farms, 1927*—Continued

Area, formation, and size group (crop acres)	Farms	Percentage distribution of farms in—				Total value of goods consumed	Income directly from the farm	Farm income
		Group A	Group B	Group C	Total			
South area:								
Breathitt—	*Number*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Dollars*	*Dollars*	*Dollars*
15 or less	11	18.2	9.1	72.7	100.0	872	−62	817
16–30	19	31.6	26.3	42.1	100.0	815	33	288
31–45	14	64.3	21.4	14.3	100.0	879	191	332
Over 45	9	33.3	33.4	33.3	100.0	994	198	558
Total	53	37.7	22.7	39.6	100.0	874	83	455
Corbin—								
15 or less	9	----------	44.4	55.6	100.0	581	−46	216
16–30	11	27.3	18.2	54.5	100.0	703	−12	164
31–45	7	42.9	14.2	42.9	100.0	709	−54	195
Over 45	3	66.7	----------	33.3	100.0	869	459	543
Total	30	26.7	23.3	50.0	100.0	684	15	225

Income from sources other than the labor of the operator, such as contributions of relatives, pensions, and interest, was the principal source of the family living for a larger proportion of farms in the south than in the north area. (Group B, Table 36.) In general, two-thirds of the families living in the south area depend for their living on the labor of the operator off the farm, supplemented by gifts, pensions, interest, and similar sources of income. In the north area, 81.7 per cent of the families studied depend for their living directly on farming, supplemented by income derived from the labor of the operator off the farm.

Here are two rather distinctive conditions—in the south area a reliance primarily on employment supplementary to farming to obtain an income and in the north area a dependence primarily on farming. Under these conditions, as might be anticipated, income derived directly from the farm is greater on the average in the north area ($186) than in the south area ($58). But of greater significance is the fact that the net farm income (that is, income derived from the farm and from the labor of the operator off the farm), is greater on the average in the south area ($372) than in the north area ($305), and the total value of the family living obtained is also greater, amounting to $805 in the south area, and to $609 in the north area.

A question suggested by the relatively better results obtained by operators who do relatively less farming is whether part-time farming should be generally encouraged in the two areas. Are farm income and value of family living relatively high in the south area because of part-time farming and relatively low in the north area because of too much dependence on the farm as a source of income? This question should be examined.

FAMILY LIVING AND SOURCE OF INCOME

In the south area 53 farms are on the Breathitt formation and 30 farms are on the Corbin formation. The proportion of farms of 31 acres and over is less on the Corbin formation than on the Breathitt formation. The explanation of this fact was discussed in connection with Tables 31 and 32. The present purpose is to call attention to the corollary fact that the proportion of operators obtaining their incomes primarily from farming is also less for farms on the Corbin formation than for farms on the Breathitt formation. The

specific question is: Is a relatively good living associated with relatively little farming? Among farms on the Breathitt formation 11 families consumed goods valued at $872, and 14 families consumed goods valued at $879. In the first group nearly three-fourths of the operators depended primarily on income from work off the farm, whereas in the second group nearly two-thirds of the operators obtained their income principally from farming. Similarly, for farms on the Corbin formation, not 1 of 9 farms with value of family living averaging $581 depended primarily on farming as a source of income, whereas 3 farms among a group of 7 with value of family living averaging $709 depended primarily on farming as a source of income. Similar relationships are found among farms located on the Breathitt formation in the north area. In each case the group of farms depending principally on part-time farming had a relatively small crop acreage and the group of farms depending principally on farming for an income had a relatively large crop acreage.

To generalize on the relationship, the tendency seems to be for the proportion of farmers depending on farming as a principal source of income to increase as the crop acreage increases and for the average value of the family living also to increase with the crop acreage. Does this lead to the conclusion that the more farming the better the living?

Such a conclusion would appear to be further supported by the fact that in the south area families on the Corbin formation, which is poorly adapted to farming, obtain a poorer living than families located on the Breathitt formation, which is relatively better adapted to farming. Similarly, in the north area families on farms located on the Breathitt formation, which is relatively less adapted to farming than the Lee formation, obtain a relatively poorer living than families occupying farms on the latter formation.

The fact is that neither part-time farming nor full-time farming, as alternative methods of earning a living, is necessarily to be recommended in all cases. More precisely the situation is this: Operators of farms in locations which provide an adequate amount of land adapted to the growing of crops can advantageously obtain their incomes principally from farming. Operators of farms in which there is relatively little land suitable for growing crops must rely primarily on income from work off the farm or from other sources to provide a living for their families. The value of the family living is greater in the south than in the north area, not because part-time farming is, in general, relatively more profitable than full-time farming, but because it is possible to a much greater degree in the south than in the north area to supplement by work off the farm the necessarily small income obtained from farms embracing land poorly adapted to farming. The explanation of this is the proximity of farms in the south area to London and Corbin and the opportunity of supplementary employment thus provided.

In general, operators obtain larger farm incomes and larger incomes directly from the farm, and the value of goods consumed by the family increases, as the number of crop acres in the farm increases. A farm containing 45 acres or more, adapted to cropping, provides an opportunity for making a good living for a family if proper enterprises are selected and good farming practices are followed. Operators of such farms are not under the necessity of relying upon outside work to

obtain a comfortable living. The inclusion in the farming system of intensive enterprises such as tobacco and dairying will, as a rule, increase the income obtained. In the analysis of the farm-management data the same general conclusion was expressed in the observation that the operation of well-organized farms of proper size "compares favorably, as a means of livelihood, with an occupation which includes nonfarming work as a chief source of income" (*9, p. 258*). That is, in general, the better the opportunities the land affords for farming, the better the opportunities the income obtained provides for living. But in the south area, where the opportunities for outside employment are relatively good, there are notable exceptions to this rule. The net farm income obtained from farms in the smallest crop acreage group is greater (and for farms on the Breathitt formation very much greater) than net farm incomes in the two next larger crop acreage groups. The value of goods consumed is also notably high for small farms located on the Breathitt formation. The conclusion is clearly suggested that, where opportunities for outside employment exist, a small farm and little or no farming is better than a slightly larger farm and relatively more farming.

FACTORS LIMITING THE AMOUNT OF THE FAMILY LIVING

In the last analysis, of course, the problem confronting the farm operator is to obtain an income adequate to provide properly for his family. The nature of the conditions confronting farm operators in Laurel County in realizing this objective can be stated rather definitely.

(1) Approximately 20 per cent of the operators of the 203 farms in the areas studied obtained their incomes principally from pensions, gifts, interest, and similar sources, not involving labor on their part. The successors of present operators of these farms are likely in most instances to be worse rather than better off with respect to the resources available for family living, for two reasons.

In the first place, under the methods of farming practiced by many of the present operators, farms in this group deteriorate rapidly. The point may be illustrated by indicating the characteristics of the crop land typical of these farms. For two farms in the south area located on the Corbin conglomerate, the farm income in both instances was negative. Nearly 50 per cent of the crop land in one farm was eroded (classes 2 and 7), and erosion on the other was in evidence on 85.9 per cent of the crop acreage (class 2). Among farms on the Breathitt formation in the same area, heavily eroded land of intermediate slope (class 7) comprised 71.7 per cent of the crop land of one farm and 66.7 per cent of another. Neither farm had an acre of class 1 crop land. These last two cases are perhaps extreme, but not exceptional as to the general character of the land in farms of this group. In the north area, 85.7 per cent of the crop land in one farm on the Breathitt formation was steep, heavily eroded hillside land.

Some farms in Group B, of course, have crop land of a type that indicates the farm should produce a good income. Probably a substantial pension does not, in general, encourage attention to the earning of an income from the farm. So far as farming possibilities are concerned the general tendency among farms of this group is for them to grow worse, rather than better. The successors of many of the present operators, therefore, probably will have a poorer farm to

start with. This is one reason why the income available for family living is likely to be less. In the second place, obviously, it is highly improbable that the succeeding operator of one of these farms will inherit or acquire the pension or other gratuitous income enjoyed by the present operator.

Group B includes 41 farms, of which 9 had 15 crop acres or less, 17 had 16 to 30 crop acres, 10 had 31 to 45 crop acres, and 5 had 46 crop acres or more. The continued operation of the farms of this group will mean that 15 to 25 families of succeeding operators, unless they are able to find additional land fit for cropping, must depend on the labor of the operator off the farm as the principal source of income and that the remainder must, for the most part, introduce improvements in present farming methods and practices, or also depend principally on work off the farm to obtain an adequate living for their families.

The difficulties confronting operators of farms in this group are based on the fact that, on the one hand, opportunities for outside work are limited, and, on the other hand, the land in some farms is too poor to yield an adequate living from the farm.

(2) A second major difficulty confronting farmers is that steep slopes, erosion, rough topography, poor soils, stones, and weeds and sprouts in varying degrees and combinations limit the amount of available crop land. Thus, of the 203 farms studied, 20 per cent had only 15 crop acres or less and 62 per cent had 30 crop acres or less. As has been shown, these small crop acreages usually are associated with crop land having characteristics that do not permit an expansion of the crop acreage. But the difficulty goes further. The actual crop acreage embraces land often wholly unfit for cultivation. The rapid deterioration of fields of this kind under cultivation makes impracticable the rotation of crops. The result is the rotation of fields. The pernicious effects of this process have been described.

The remedy is not to be found in the rotation of crops on the hillside land, because erosion can be controlled only by keeping these fields in grass. Moreover, where there is little or no land of moderate slope available keeping the hillsides in grass and cultivating only the land of moderate slope is impracticable. For example, farmer No. 175 owned 90 acres. He operated 80 acres, of which 38.75 acres were classed as crop land. This crop land was described as follows: 33.50 acres, or 86.5 per cent, heavily eroded, steep, hillside land with shale or stones scattered over the surface of the fields and many weeds and sprouts (class 9); 2 acres, or 5.2 per cent, of smooth to rolling land, heavily eroded and covered with surface shale (class 3); 3 acres, or 7.7 per cent, of steep, hillside land in good physical condition (class 8); 0.25 acre, or 0.6 per cent, rock outcrop. (Class 11.) In 1927, this farmer rented out 10 acres and cropped 16.5 acres. His net income derived directly from the farm was $84. He made his living by work away from the farm.

Another example: Farmer No. 185 owned 145 acres, of which he rented out 11 and operated 134. Sixty acres were classed as crop land, which was described as follows: 54 acres, or 90 per cent, of heavily eroded, steep land like that in farm 175 (class 9); 6 acres, or 10 per cent, of smooth land in good condition, cleared in 1912. (Class 4.) In 1927 this farmer had 26.5 acres in crops. His net income derived

directly from the farm was minus $311. The $300 he earned by work off the farm left him a net farm income of minus $11.

The problem of obtaining a better living for farmers situated like these two (who are typical of many) obviously is not solved by more farming. It is equally true that the introduction of better farming methods would offer only a limited opportunity for betterment when only 6 acres or less is the maximum area suitable for cultivation. In short, no plan of organization based on a farm economy exclusively can promise substantial improvement in the economic basis of living on farms of this type.

Two courses remain open for improving the condition of operators of farms of this type—a change of location for operators of these farms or a change in the type of economy. A change of location is essential unless a basis for part-time farming can be established by the development of local industries to provide employment supplementary to farming. Such a development would be facilitated by the construction of a few good roads, and such roads would also provide better access to part-time employment by operators of farms of this type.

An increase in available supplementary employment, in addition to affording more efficient utilization of the operator's time, would have the important corollary effect of permitting the practice of a type of farming adapted to the utilization of small acreages and would tend to restrict the practice of cropping steep hillsides. Very small acreages could be utilized primarily for home gardens. Where larger acreages are available, a considerable income could be obtained from poultry and dairy products and tobacco could be grown as a cash crop.

(3) Under present conditions there is little question that many farmers derive little, if any, advantage from a large part of the acreage they own. As a rule, the farm wood lots contribute no regular income to the farm. The pastures are extremely poor, chiefly because steep land has been eroded and worn out by cropping before reverting to pasture. Because of the exploitative methods of utilization, the crop land, also, is much less productive than it might be. Under present methods of utilization many farmers own land that is not worth the taxes they pay on it. In many instances a reduction of the total acreage in the farm would improve the economic position of the operator.

Crop land should be confined to land adapted to that purpose. Long-lay pastures should be established on the slopes. Steep hillsides should be allowed to revert to woodland. There seems to be little present opportunity for the individual wood-lot owner to realize an assured annual income from his holding. The most promising method of improving this situation appears to be the development of some form of cooperative organization including 300 or 400 farmers. Such an organization would be in a position to make contracts with paper mills, mines, railroads, and other manufacturers and users of timber on the basis of an assured annual volume of pulpwood, mine timbers, ties, stave bolts, etc. Local labor could be utilized in cutting, skidding, and hauling. The logs could be sawed by a portable mill operated under cooperative ownership.

Probably no plan of economic and social reorganization, however, will prove adequate to establish a sound basis of living for the more isolated and inferior farms. The extent to which readjustments can be confined to changes within the area depends on the relation of

present and potential resources to the present and potential population of the area. Attention is directed to this phase of the problem in the next few pages.

POPULATION AND POPULATION CHANGES IN RELATION TO LAND UTILIZATION

DENSITY OF POPULATION

In discussing the process of settlement of the Kentucky mountain region, attention was directed to the fact that the density of the population has steadily increased since the last decade of the eighteenth century. Until 1900 this increase was almost entirely genetic and since then very largely so. The population density of the rural mountain districts was 48.8 persons per square mile in 1920. In Laurel County the density of population in 1920 was 40.5 if the town of London is excluded and 44.3 if London is included. For the county as a whole, therefore, the density of population is not so great as for the mountain region as a whole. On the other hand, the density for the whole mountain region is affected by the relatively populous mining counties. Between 1910 and 1920 there was a slight decrease in the total population of Laurel County, but this decrease was more than offset by a gain of 1,295 in the total population between 1920 and 1930.

The north and south areas, in which farms were visited in the present study, are relatively populous portions of Laurel County. The north area is relatively isolated, compared with the south area. Population trends in each area will, therefore, indicate in a general way what is happening to the population in relatively isolated areas in comparison with areas closer to towns and to the State highway.

The families studied resided in an area of 27.57 square miles, of which the north area comprised 16.57 square miles and the south area 11 square miles. In 1918 density of population in the two areas was 43, and 10 years later, in 1928, the density was 45.7. (Table 37.) The increase amounted to 2.7 persons per square mile, or 6.2 per cent. The ratio of increase was greater for males than for females. In the north area the increase was only 1.4 persons per square mile or 3.4 per cent (Table 37), whereas in the south area the increase amounted to 4.6 persons per square mile, or 9.9 per cent. This relatively large increase in the population of the south area brought the population there to 51.5 persons per square mile in 1928. In the north area the density was 41.8 in 1928. A population of this density is large, in view of the limitations of the agricultural and other economic resources of the areas studied.

TABLE 37.—*Population and population changes, north and south areas, by sex, 1918 and 1928*

TOTAL POPULATION

Sex	North area		South area		Both areas	
	1918	1928	1918	1928	1918	1928
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Male	323	341	270	294	593	635
Female	346	351	246	273	592	624
Total	669	692	516	567	1,185	1,259

TABLE 37.—*Population and population changes, north and south areas, by sex, 1918 and 1928*—Continued

POPULATION PER SQUARE MILE [1]

Sex	North area		South area		Both areas	
	1918	1928	1918	1928	1918	1928
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Male	19.5	20.6	24.5	26.7	21.5	23.0
Female	20.9	21.2	22.4	24.8	21.5	22.7
Total	40.4	41.8	46.9	51.5	43.0	45.7

INCREASE OF POPULATION, 1918–1928

		Per cent		*Per cent*		*Per cent*
Male		5.6		8.9		7.1
Female		1.4		11.0		5.4
Total		3.4		9.9		6.2

[1] The north area contained 16.57 square miles and the south area 11 square miles.

The general effects of pressure of population on economic and social conditions in the area are rather clearly exhibited by the results of the study. Agriculturally, the pressure of population has led to attempts by many farmers to utilize for the production of crops land that is wholly unadapted to that purpose. The scarcity of available land has led to overcropping of fields on these farms. The fields have thus been depleted of soil fertility, both by erosion resulting from cropping steep slopes, and from continuous cropping. The pernicious effects of these practices tend to be cumulative. The fields are worn out and are recaptured by sprouts and briers. Old fields are recleared. The farm economy on these farms degenerates into a routine of utter futility, based essentially on the rotation of fields and the growing of corn. The less productive the land becomes, the more important it is that the crops obtained contribute directly and immediately to the family living. Subsistence farming, the so-called self-sufficing agriculture,[23] is enforced by the necessity of living, while failing to provide adequate, and tending to provide less and less, living necessities for families on these farms.

The inadequate agricultural basis of living provided by farms of this type has important effects on the individual, the population, and the community. The central factor in the whole situation is economic and social isolation. The geographic factors are probably the original foundation of this isolation. But geographical isolation is succeeded by barriers of an economic and social sort that tend to persist long after geographical obstacles have been surmounted.

The problems in the mountains to-day take their special character from the fact that the railroad, the highway, the automobile, the telephone, and other means of communication have to a considerable extent pierced the geographical barriers isolating the mountain population, creating for these communities rather difficult problems of adjustment. The barriers of economic and social isolation are crumbling before the impact of new contacts, new ideas, and wider

[23] Subsistence farming is inaptly called "self-sufficing agriculture." It is not agriculture and it does not suffice.

horizons. The effect of these new forces and influences on the individual emerges primarily in his capacity to see himself in relation to a wider environment and in a consequent development of his individuality. A growing consciousness of the contrast between the privileges and opportunities provided by the home community and those offered elsewhere is inevitable. The chief objective manifestation of this is found in the migration of young people to other communities.

SONS AND DAUGHTERS AWAY FROM HOME

Among the families studied, the children who left home averaged between 19 and 20 years of age at the time of leaving. The average age of daughters on leaving home was slightly less than that of sons. Of the total number of sons and daughters away from home daughters comprise a greater proportion than sons, but a rather interesting contrast in this particular is offered by the south and north areas. In the south area, in contrast to the north area, the proportion of sons away is greater than the proportion of married daughters. The same is true as to the number of single daughters. (Table 38.) This difference probably reflects, in part, the influence of a greater degree of isolation of farms in the north area compared with farms in the south area. The marriage of daughters normally involves a change to the homes of their husbands. When the larger proportion of children leaving home are daughters, and marriage of daughters is the principal occasion of departure, a relatively low mobility of the population is indicated.

TABLE 38.—*Sons and daughters away from home, north and south areas, classified by sex and by marital status of daughters, 203 families, 1927–28*

NUMBER AWAY

Member of family	North area	South area	Both areas
	Number	*Number*	*Number*
Sons	91	87	178
Married daughters	121	54	175
Single daughters	7	15	22
Total	219	156	375

NUMBER AWAY PER FAMILY

Sons	0.7	1.0	0.9
Married daughters	1.0	.7	.8
Single daughters	.1	.2	.1
Total	1.8	1.9	1.8

PERCENTAGE AWAY

	Per cent	*Per cent*	*Per cent*
Sons	41.6	55.8	47.5
Married daughters	55.2	34.6	46.7
Single daughters	3.2	9.6	5.8
Total	100.0	100.0	100.0

This situation and the inference, as applied to the north area, are supported by collateral data. For example, the same line of reasoning would suggest that in the north area a larger proportion of the children away from home would reside in the area or under conditions similar to

those at home. Measures of the validity of these inferences are to be found in a classification of children away from home in each area by present residence and by present occupations. What becomes of the assumption that children in the north area will show less mobility both as to movement and as to occupation than children in the south area?

In the case of 178 sons away from home, 48.3 per cent in the south area as compared with 27.4 per cent in the north area had their present residences in a State other than Kentucky. That, perhaps, is less significant than the fact that 36.8 per cent of the sons away from home in the south area, in contrast to 58.3 per cent away from home in the north area, continued to reside in mountain counties. (Table 39.) The contrast between the two areas as to present residence of married daughters away from home is similar. (Table 39.) It is difficult to believe that these differences are wholly fortuitous or that they are unrelated to differences in the kind or in the degree of cultural forces, economic and social, that have influenced individuals in the two areas. It is less difficult, in fact it is reasonable, to suppose that these differences and their consequences will be less evident in the future.

TABLE 39.—*Sons and married daughters away from home, north and south areas, by present locations, 203 families, 1927–28*

Present location	North area		South area		Both areas	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
SONS AWAY						
In area	18	19.8	11	12.6	29	16.3
In Laurel County	23	25.3	5	5.8	28	15.7
In adjacent county	6	6.6	8	9.2	14	7.9
In mountain region	6	6.6	8	9.2	14	7.9
Elsewhere in Kentucky	13	14.3	13	14.9	26	14.6
In another State	25	27.4	42	48.3	67	37.6
Total	91	100.0	87	100.0	178	100.0
MARRIED DAUGHTERS AWAY						
In area	36	29.8	9	16.7	45	25.7
In Laurel County	42	34.7	7	13.0	49	28.0
In adjacent county	11	9.1	6	11.1	17	9.7
In mountain region	3	2.5	4	7.4	7	4.0
Elsewhere in Kentucky	9	7.4	12	22.2	21	12.0
In another State	20	16.5	16	29.6	36	20.6
Total	121	100.0	54	100.0	175	100.0
SONS AND MARRIED DAUGHTERS AWAY						
In area	54	25.5	20	14.2	74	21.0
In Laurel County	65	30.7	12	8.5	77	21.8
In adjacent county	17	8.0	14	9.9	31	8.8
In mountain region	9	4.2	12	8.5	21	5.9
Elsewhere in Kentucky	22	10.4	25	17.7	47	13.3
In another State	45	21.2	58	41.2	103	29.2
Total	212	100.0	141	100.0	353	100.0

As to occupational mobility, also, the evidence is that the north area has less than the south area. In the north area, the farmer's daughter marries a farmer, and the farmer's son follows the occupation of his father. Such, at any rate, is the tendency to a much greater degree in the north than in the south area. In the north area 40.6

per cent of the sons away from home were farmers; in the south area, 16.3 per cent. (Table 40.) In the north area, 64.7 per cent of the married daughters away from home were wives of farmers; in the south area, 31.4 per cent. (Table 41.)

TABLE 40.—*Sons away from home, north and south areas, by present occupations, 203 families, 1927–28*

Occupation	Sons away from home					
	North area		South area		Both areas	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
Farmer	37	40.6	14	16.3	51	28.8
Tradesman	9	9.9	13	15.1	22	12.4
Professional service	10	11.0	20	23.2	30	17.0
Merchant or dealer	5	5.5	6	7.0	11	6.2
Public service	9	9.9	11	12.8	20	11.3
Laborer	21	23.1	22	25.6	43	24.3
Total	91	100.0	[1]86	100.0	177	100.0

[1] Occupation was not reported for 1 of the 87 sons away from home in the south area.

TABLE 41.—*Married daughters away from home, north and south areas, by present occupations of husbands, 203 families, 1927–28*

Occupation of husband	Married daughters away from home [1]					
	North area		South area		Both areas	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
Farmer	77	64.7	16	31.4	93	54.7
Tradesman	4	3.3	5	9.8	9	5.3
Professional service	2	1.7	6	11.8	8	4.7
Merchant or dealer	2	1.7	1	1.9	3	1.8
Public service	10	8.4	7	13.7	17	10.0
Laborer	24	20.2	16	31.4	40	23.5
Total	119	100.0	51	100.0	170	100.0

[1] Excluding 5 persons for whom the information was not given.

MIGRATION OF CHILDREN AND SIZE OF FARMS

Is the migration of children from the better or from the poorer land, from the larger or from the smaller farms? The immediate effectiveness of migration as a means of adjusting population to resources would be greater, of course, if the process were restricted to the poorer land and the less favorable locations. However, there is a theoretical basis for supposing that the tendency may be precisely opposite—that the children of the operators of the larger and more prosperous farms will be first to migrate. The supposition may be based both on biological and economic considerations. It may be that the better land and larger farms are occupied by the biologically superior portions of the population, so that migration takes place principally from among this element of the population, which is endowed with the initiative to challenge life, and the capacity to grasp the instruments of living in a more complicated and competitive environment. On purely economic grounds, also, through the enjoyment of superior educational opportunities, occasional travel, and similar influences, children of the more prosperous operators are more likely than the children of oper-

ators less fortunately situated, to acquire training and experience that would influence them to leave the mountains.

The data of the study provide no conclusive answer to the question. It is true that of the number of children away from home in the south area, the greater proportion are from farms having 30 crop acres or less. (Table 42.) But the number away per family is greater for farms in the larger crop-acreage groups. The north and south areas exhibit marked differences in this respect. In the north area the proportion of children from farms of 30 crop acres or less is much greater than in the south area, and the number per family from very small farms in the north area is also large, both as compared with farms of similar size in the south area and with respect to all but the largest crop-acreage group in the north area. Migration of children from the very small farms in the north area is probably enforced, to a much greater degree than in the south area, by the greater dependence on farming as a source of family income in the former than in the latter area.

TABLE 42.—*Sons and daughters away from home, north and south areas, classified by size of farm occupied by parents, 203 farms, 1927–28*

NUMBER AWAY

Size group (crop acres)	North area	South area	Both areas
	Number	*Number*	*Number*
15 or less	42	30	72
16–30	102	54	156
31–45	42	45	87
Over 45	33	27	60
Total	219	156	375

NUMBER AWAY PER FAMILY

15 or less	2.1	1.5	1.8
16–30	1.8	1.8	1.8
31–45	1.4	2.1	1.7
Over 45	2.5	2.2	2.4
Total	1.8	1.9	1.8

PERCENTAGE AWAY

	Per cent	*Per cent*	*Per cent*
15 or less	19.2	19.2	19.2
16–30	46.6	34.6	41.6
31–45	19.2	28.9	23.2
Over 45	15.0	17.3	16.0
Total	100.0	100.0	100.0

The central problem as to the point in question, however, is not touched by the data of Table 42. That problem is suggested in the question: Where are the children away from home located? It is of very real import, therefore, to know the extent to which children of present operators are migrating from the mountain area, and whether and to what extent this migration is contributing directly to a solution of the land problem by the evacuation of the less prosperous farms. Some further light is thrown on this question by combining the data of Tables 39[24] and 42.

[24] Modified to include unmarried daughters away from home.

When this is done the contrast between the north and the south areas, indicated by Table 42, is more sharply defined. (Table 43.) In the north area, children leaving home tend to stay in the mountains, no matter what the size of the farm, but with the tendency to leave the mountains somewhat greater among children from the smaller farms. In the south area, children tend to leave the mountains, no matter what the size of the farm, but with the tendency to leave the mountains somewhat greater among children from the larger farms.

TABLE 43.—*Sons and daughters away from home, north and south areas, classified by present location and number of crop acres in farms occupied by parents, 1927–28*

NUMBER IN EACH SIZE GROUP

Location	North area			South area		
	30 crop acres or less in parents' farm	Over 30 crop acres in parents' farm	Total	30 crop acres or less in parents' farm	Over 30 crop acres in parents' farm	Total
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
In mountains	94	53	147	41	23	64
Not in mountains	50	22	72	43	49	92
Total	144	75	219	84	72	156

PERCENTAGE IN EACH SIZE GROUP

	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
In mountains	65.3	70.7	67.1	48.8	31.9	41.0
Not in mountains	34.7	29.3	32.9	51.2	68.1	59.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

The tendency of children from the north area to stay in the mountains suggests that the relatively greater geographic isolation of that area has reduced economic and social barriers to migration from the mountains to a smaller degree than in the south area where this tendency is reversed. The fact also that in the north area children from small farms leave the mountains in greater proportion than children from large farms suggests that migration from the north area is to a considerable degree enforced by the limitations of farming as a source of livelihood. The presumption suggested by the figures is that lack of local opportunity is a more potent factor in inducing children in the north area to leave the mountains than is the consciousness of broader opportunities elsewhere, combined with the desire and the resources to grasp them.

In the south area, on the other hand, a greater degree of accessibility to outside contacts appears to be manifested in a greater consciousness of opportunities outside the mountains combined with the pursuit of these opportunities by a greater proportion of the children from large than from small farms. This tendency for migration from the mountains to be associated with the more prosperous farms in the south area may, in fact, be more pronounced than the figures of Table 43 indicate, because the prevalence of part-time farming often causes relatively good incomes to be associated with

relatively small farms, thus obscuring the normal relationship between income and size of farm.

Contrasts between the north area and the south area—between relatively isolated and relatively accessible population groups—are of moment only to the extent that they suggest a clue to the probable effect on the younger generation of mountain children of changes now under way in the mountains. Will the children in localities like the relatively isolated north area tend more and more to leave the mountains, like the children in the more accessible south area, as geographic barriers to external economic and social influences disappear? The figures of this study suggest an affirmative answer, and that conclusion is too strongly supported by the history of population movements to require elaborate substantiation in its present application.

The implications of such a conclusion do not, however, necessarily lead to a solution of the central problem of adjustment of population to resources. Although the age distribution of the population of the north and south areas indicates that heavy emigration has taken place (*11, p. 80*) from both areas during the 10-year period, 1918–1928, the total population of each area increased in the same period, as shown by Table 37. Since 62.8 per cent of the present operators were born in Laurel County and 93.9 per cent were born in Kentucky, immigration does not appear to be a significant factor in this increase. It is in the effect of changed conditions on the composition and characteristics of the population with particular reference to changes in birth rates and death rates that light on this further aspect of the problem must be sought.

COMPOSITION AND CHARACTERISTICS OF THE POPULATION [25]

In 1928 families averaged 4.8 persons per family and 5.3 persons per household. The average number of rooms used per family was 4.5, and there were on the average only 2.5 bedrooms for a household of 5.3 persons. The houses were equipped with practically none of the conveniences and facilities of the modern home. Only 1 in every 40 houses in the area had either a central heating or lighting system. With these exceptions there was no modern equipment in the houses.

Nevertheless, there were a number of attractive, comfortable farm houses of adequate size in both areas. The unfavorable conditions indicated by the averages reflect the evils associated with attempts to farm land unsuited to that use, poor farming practices, and the consequent inadequacy of the family living provided by many farms. But a substantial number of families who live in these areas are no longer occupying isolated mountain homes. Isolation is a relative matter as it affects individuals, families, and communities.

The impact of new ideas and influences even on the more isolated families to-day is much greater than might be inferred from a first-hand contact with their present situation. News travels rapidly in the mountains. The significant fact is that the character of word-of-mouth contacts has changed. These mountain communities have long been highly self-contained social and economic units. Gossip dealt with the routine of life among familiar persons and conditions. News of change in a changing world is a part of the routine of life,

[25] See also Kentucky Agricultural Experiment Station Bulletin No. 301 (*11*).

but such news is highly personal, novel, and significant when it touches the lives of individuals and the customary mode of living in a self-contained community. The changed conditions which have given a new character to the social and economic environment of the mountain community have profoundly affected the individual. The nature of these effects suggests that corresponding changes have taken place in the composition and characteristics of the mountain population.

A comparison of the age distribution and sex composition of the population in 1918 and 1928 confirms, in general, the conclusions reached in the preceding section in regard to the migration of sons and daughters from the north and south areas, respectively. The analysis at this point is based on the data of Tables 44 and 45.

TABLE 44.—*Percentage of population in specified age groups, north and south areas, by sex, 1918 and 1928*

Age (years)	North area				South area			
	Ratio of males to total male population		Ratio of females to total female population		Ratio of males to total male population		Ratio of females to total female population	
	1918	1928	1918	1928	1918	1928	1918	1928
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
0–9	25.1	23.2	25.4	26.5	29.3	28.9	25.2	27.1
10–19	22.9	25.5	27.7	23.1	25.6	27.5	27.7	24.5
20–29	12.1	10.6	10.7	13.1	11.1	9.2	13.0	10.6
30–39	11.4	12.0	10.7	11.4	9.6	6.8	12.6	12.5
40–49	11.8	10.8	11.0	8.0	9.6	11.2	6.9	10.6
50–59	5.9	8.5	5.2	8.2	5.9	9.9	8.1	8.1
60	10.8	9.4	9.3	9.7	8.9	6.5	6.5	6.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 45.—*Males per 100 females, north and south areas, by age groups, 1918 and 1928*

Age (years)	North area		South area		Age (years)	North area		South area	
	Males per 100 females		Males per 100 females			Males per 100 females		Males per 100 females	
	1918	1928	1918	1928		1918	1928	1918	1928
	Number	*Number*	*Number*	*Number*		*Number*	*Number*	*Number*	*Number*
0–9	92.0	84.9	127.4	114.9	40–49	100.0	132.1	152.9	113.8
10–19	77.1	107.4	101.5	120.9	50–59	105.6	100.0	80.0	131.8
20–29	105.4	78.3	93.8	93.1	60	109.4	94.1	150.0	105.6
30–39	100.0	102.5	83.9	58.8					

In making the following comparisons it is recognized that the age and sex groups are small and, therefore, subject to wide variation in the percentage distribution of the population because of possible differences in the number of births in the two decades. Although this consideration may invalidate conclusions drawn from comparisons between age and sex groups, it does not preclude examination of the data to test the consistency of the tendencies suggested with those exhibited by other data of the study.

In the north area in 1918 there were 92 males per 100 females among children under 10 years of age. Ten years later, in 1928,

among children 10 to 19 years of age there were 107.4 males per 100 females. The proportion of females in the 10 to 19 age group was smaller and the proportion of males was larger in 1928 than in 1918. The decline in the proportion of females may be attributed principally to marriage prior to 1928 of females who were 10 to 14 years old in 1918. Females who leave the mountains tend to do so at the time they marry, that is, from 16 to 19 years of age. The preponderance of males in the 10 to 19 age group in the north area in 1928 in contrast to 1918 suggests a tendency for marriages of this type to increase.

In the south area, also, the migration of females at a younger age than males has the same general effect on the population in the 10 to 19 age group as in the north area. But in the south area this migration of females continues to a later age, probably because women in the south area have opportunities for marriage or employment outside the area superior to those of women in the north area. As a consequence of this migration of women from the south area, the proportion of females in the 20 to 29 age group, as well as in the 10 to 19 age group, is less in 1928 than in 1918.

The low ratio of males to females in the 10 to 19 age group in 1918 in the north area appears to be due to the high ratio of female to male births or to a higher death rate among males, particularly in the 10 to 14 age group. The low sex ratio (78.3) in 1928 among persons in the north area 20 to 29 years of age is probably due, in part, therefore, to the excess in the number of females among children under 20 years of age in 1918, as well as to the migration of males, and there is the possibility, of course, of disturbing influences attributable to the war.

In the south area the situation is different. An excess in the number of males among children 10 to 19 years of age in 1918, is changed among the 20 to 29 age group to a ratio of 93.1 males per 100 females. And it is significant to note that a ratio only slightly higher prevailed for this same age group in 1918. That is, in line with the analysis of the preceding section, the process of migration has been under way longer in the south than in the north area, and its effects on the composition and characteristics of the population are more pronounced in the former area. The migration of males in the 20 to 29 age group between 1918 and 1928, reduced the sex ratio in the 30 to 39 age group to 58.8 in the latter year. In the 30 to 39 age group also, the ratio of males to all males declined from 9.6 per cent in 1918 to 6.8 per cent in 1928.

The population of the north area in 1918 shows a balanced ratio between the sexes for the adult groups and may be accepted as a fair representation of the situation before changed conditions began to upset the equilibrium of the sexes. The consequences of these disturbing influences may be discerned, in their early effects, in the changes in the population of the north area, and in their more mature effects, by changes in the population of the south area. This relationship furnishes an additional basis for the inference that the isolated portions of the mountain area will tend to undergo changes similar to those now under way in the less isolated portions, when the new influences at work penetrate present social and geographic barriers.

So far as the history of the 10 years, 1918 to 1928, is concerned, the population of the north area has shown a tendency to decline. The emigration of children is somewhat offset by the return to the area of older persons who have previously migrated. Old houses vacated are about equally replaced by new houses or houses reoccupied. There were in the area 147 occupied houses in 1918 and 144 in 1928. Families move in to replace families moving out. Birth rates tend to decline. The population increased only slightly between 1918 and 1928. The present economic basis of living is inadequate to support a larger population. The pressure of population tends to induce emigration. Between 1920 and 1930, according to the 1930 census of population, the population of district 3 declined from 2,691 to 2,579, while the population of district 6, numbering 3,615 in 1920 and 3,616 in 1930, remained practically unchanged. The north area is included in districts 3 and 6.

A consideration of the same factors in the south area reveals significant differences. The part-time farming which has developed in the south area has mitigated to a considerable extent the adverse effects of the decline in income from supplementary industries such as mining and forestry, associated with farming in the mountains at an earlier period. As a consequence, the number of families residing in the area has tended to increase rather than diminish during the 10-year period. (Table 46.) The number of houses vacated during the period indicates, in comparison with the north area, relatively little economic pressure leading to emigration. On the contrary, in the south area 23 additional houses, of which 19 represented new construction, were occupied, and only 5 were vacated during the 10-year period. Expansion in the number of occupants kept pace with expansion in the number of houses. In the north area 17 additional houses, of which 15 represented new construction, were occupied, but 18 were vacated during the 10-year period. Moreover, while the number of houses was increasing by 13, the number of occupied houses was decreasing by 3.

TABLE 46.—*Changes in the number of houses and in the number of old and new houses occupied, north and south areas, by years, 1918–1928*

NORTH AREA

Year	Habitable houses		Cumulative change in—		House occupied which was—		Houses vacated	Houses destroyed
	Total	Occupied	Habitable houses	Occupied houses	Formerly vacant	New		
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1918	155	147			0	0	3	1
1919	154	143	−1	−4	0	3	3	0
1920	157	143	2	−4	0	4	0	0
1921	161	147	6	0	1	1	0	0
1922	162	149	7	2	0	2	6	0
1923	164	145	9	−2	1	1	0	0
1924	165	147	10	0	0	4	2	0
1925	169	149	14	2	0	0	1	0
1926	169	148	14	1	0	0	1	1
1927	168	146	13	−1	0	0	2	0
1928	168	144	13	−3				
Total or average	163	146	13	−3	2	15	18	2

TABLE 46.—*Changes in the number of houses and in the number of old and new houses occupied, north and south areas, by years, 1918–1928*—Continued

SOUTH AREA

Year	Habitable houses		Cumulative change in—		House occupied which was—		Houses vacant	Houses destroyed
	Total	Occupied	Habitable houses	Occupied houses	Formerly vacant	New		
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1918	107	98			0	0	0	[1] 1
1919	106	98	−1	0	2	0	0	0
1920	106	100	−1	2	1	4	0	0
1921	110	105	3	7	1	2	0	0
1922	112	108	5	10	0	1	3	0
1923	113	106	6	8	0	3	1	0
1924	116	108	9	10	0	3	0	0
1925	119	111	12	13	0	2	1	0
1926	121	112	14	14	0	3	0	0
1927	124	115	17	17	0	1	0	0
1928	125	116	18	18				
Total or average	114	107	18	18	4	19	5	1

[1] Vacant in 1918.

Pressure of population has been more severe in the north than in the south area during the 10-year period, although the density of population is greater in the latter area. This difference in the pressure of population in the two areas is further confirmed by figures of the 1930 census of population for districts 1 and 2, which include the south area. Between 1920 and 1930, the population of district 1 (excluding London) increased 790, from 1,528 to 2,318, and the population of district 2 increased 1,752 from 2,246 to 3,998. These increases are in contrast to a net decrease during the same period in the population of districts 3 and 6 which include the north area.

Whatever the present tendencies may be it is obvious that pressure of population has had important effects on economic and social conditions in both areas. As to the economic manifestations of the pressure of population enough has been said. As to the social and institutional aspects of the problem, the data of the study permit only rather general observations. But it is pertinent here to give precise statement to two general questions: (1) What measures can be taken to obtain a better adjustment of population to resources? (2) What measures can be taken to ameliorate present economic and social conditions while long-time adjustments are in progress?

Some suggestions bearing on these questions will be made in the recommendations to follow, but preliminary to that a general sketch of certain community aspects of the problem is necessary.

COMMUNITY CONDITIONS AND PROBLEMS

Changed and changing social and economic conditions in the mountains raise many problems of adjustment relating to community institutions and services. The data of the present study permit no more than a few general suggestions regarding the nature and significance of these problems.

CHANGED BASIS OF FARMING

Undoubtedly the depletion of the forests and the consequent decline of the logging industry have been of serious consequence to many

farmers in Laurel County. For a time mining developments around Pittsburgh and East Bernstadt afforded employment to part-time farmers, but the number now employed is not commensurate with the need for work. Occupants of small farms in the relatively inaccessible north area and in similar areas elsewhere have found no adequate source of outside employment. The isolated farmer has been compelled to rely principally on farming as a source of livelihood, whereas the edaphic limitations of the area make impossible on many farms the earning of an adequate income from farming.

In addition to other consequences a marginal group of farms has appeared. Two principal conditions explain the existence of these farms. The first rests on physical conditions, primarily edaphic, which are practically insurmountable at present; the second rests on social inertia, growing out of the long isolation of the population. The effect of the tendency to stay in the mountains in the face of adverse conditions has not been specifically considered although some data bearing on the phenomenon have been presented showing that the tendency is most pronounced in the isolated area.

The existence of land marginal for farming usually is the result of a combination of physical and economic conditions over which the individual has little control. But it is the occupancy of that land for farming that creates the marginal farm. The land problem, in its present aspect, emerged when the land became marginal for agriculture and continued to be occupied for that purpose. The solution of that problem must, of necessity, begin with the man on the land.

PROBLEM OF THE MARGINAL FARMER

The farmer occupying one of these marginal mountain farms, if pictured in his present situation against the background of his own life, must appear as a rather bewildered individual. He is not a migrant like the sons and daughters who found opportunity in new and strange conditions. But he is a mover. His moves are from farm to farm. He fights defeat by holding fast to familiar ways; but, holding fast, he is ever defeated. The first approach to a solution of the land problem in the mountains is to face the problem of these marginal farmers. Theirs is a problem primarily of psychological and social adjustment. The conditions under which the marginal farmer lives may not satisfy the demands of a minimum standard of living; they may not satisfy him. It does not follow that he would thrive better elsewhere, under the handicap of adapting himself to new conditions. To remove the marginal farmer from his present environment would probably have the effect, in many instances, of shifting him from a condition that is bad to one that is worse.

Data on the changes of occupancy of 294 farms during the period 1918 to 1928 are available for the north and south areas. There were 245 farms reported occupied in 1918, 49 per cent of which were occupied by the same operators in 1928. In other words, of the 260 occupied farms in the two areas in 1928, only 120, or 46.2 per cent, were occupied by the same operators in 1918. Operators of these 120 farms have managed to develop an economy that had in it the elements of stability under the conditions of the last decade. (Table 47.)

TABLE 47.—*Changes in the occupancy of 294 farms, north and south areas, 1918–1928*

Item	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928
Farms with a habitable house (beginning of year):											
Occupied—number	245	241	243	252	257	251	255	260	260	261	260
Vacant—do	17	19	20	19	17	26	26	28	30	31	33
Total—do	262	260	263	271	274	277	281	288	290	292	293
Farms without a habitable house (beginning of year)—number	32	34	31	23	20	17	13	6	4	2	1
Total—do	294	294	294	294	294	294	294	294	294	294	294
Farms with a habitable house (end of year):											
Not changing occupants during year—number	227	211	218	233	224	227	216	228	229	232	-----
Changing occupants during year—do	14	27	25	19	24	23	37	30	29	27	-----
Built and occupied during year—do	0	3	8	3	3	4	7	2	3	1	-----
Vacant house occupied during year—number	0	2	1	2	0	1	0	0	0	0	-----
Vacant during year—do	16	17	19	17	17	25	26	28	30	31	-----
Vacated during year—do	3	3	0	0	9	1	2	2	1	2	-----
Total—do	260	263	271	274	277	281	288	290	292	293	-----
Farms without a habitable house (end of year):											
No house at beginning of year—number	32	31	23	20	17	13	6	4	1	1	-----
House destroyed during year—do	2	0	0	0	0	0	0	0	1	0	-----
Total—do	34	31	23	20	17	13	6	4	2	1	-----
Grand total—do	294	294	294	294	294	294	294	294	294	294	-----
Percentage distribution of occupants in 1928 by first year of occupancy—per cent	46.2	1.2	6.2	4.2	4.6	2.7	4.6	6.9	6.2	6.5	10.7
Percentage of first-year occupants remaining on the same farm in subsequent years:											
1918—per cent	100.0	92.7	82.9	76.3	70.6	64.9	61.6	56.7	53.1	51.0	49.0
1919—do	-----	100.0	57.1	42.9	35.7	28.6	28.6	21.4	21.4	21.4	21.4
1920—do	-----	-----	100.0	78.1	78.1	68.7	62.5	56.2	56.2	50.0	50.0
1921—do	-----	-----	-----	100.0	88.2	61.8	50.0	38.2	35.3	32.4	32.4
1922—do	-----	-----	-----	-----	100.0	75.1	66.7	62.5	50.0	50.0	50.0
1923—do	-----	-----	-----	-----	-----	100.0	70.4	44.4	33.3	25.9	25.9
1924—do	-----	-----	-----	-----	-----	-----	100.0	57.1	50.0	46.4	42.9
1925—do	-----	-----	-----	-----	-----	-----	-----	100.0	68.2	47.7	40.9
1926—do	-----	-----	-----	-----	-----	-----	-----	-----	100.0	65.6	50.0
1927—do	-----	-----	-----	-----	-----	-----	-----	-----	-----	100.0	53.1
1928—do	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	100.0

The number of changes averaged 30 annually over the 10-year period, or approximately 10 per cent of the total number of farms. There were 295 changes made among a total of 304 individuals and 294 farms. Deducting the 120 farms which did not change occupants, leaves 174 farms which were shifted about among 184 farmers. In 1918, on 32 farms there was no house. Houses were built on 34 farms during the period, but the increase in the number of farms occupied was only 15. For the remaining 19 farms on which houses were constructed, an equivalent number of occupied houses were vacated or destroyed—17 vacated houses were not reoccupied and 2 occupied houses were destroyed.

In 195 of the 295 changes of operator, or 66.1 per cent of the cases, the succeeding operator was not related to the previous operator. In 48 cases a son and in 16 cases a son-in-law was the successor. In seven instances an operator returned, after one or more years, to a farm previously occupied by him during the period.

The situation presents a picture of two opposing forces in juxtaposition—one economic, the other social. Economic forces have so changed the requirements for successful farming that many farms

formerly occupied on the basis of employment in industries supplementary to farming, such as lumbering and mining, are now marginal. Social forces, on the other hand, exert a powerful influence on individuals, tending to cause them to remain on these farms. The extent of such influences is likely to be underestimated unless account is taken of the strong emotional attachment which leads families to cling tenaciously to their native environment.

Pressure of population leads to two major economic difficulties. In addition to enforcing the utilization of land marginal for farming, it tends to create a false impression of a scarcity of labor. The difficulties of maintaining a few patches of crop land against the inroads of briers and sprouts tend to convince the farmer who is confronted with these difficulties that he needs the help of a large family in the struggle. Large families are typically associated with subsistence farming. Family labor is substituted for capital investment.

Changes in the number and distribution of the population which may be anticipated from the normal operation of economic and social forces may ultimately correct the more serious maladjustments in land utilization, but immediate attention should be given to practical measures for improving living conditions by stimulating better farm management and by expanding the opportunities provided, particularly to the occupants of marginal farms, of supplementary employment.

LOCAL INDUSTRIES AND MARKETS

Depletion of the forest and coal resources of Laurel County has been counterbalanced, to some extent, by employment incident to improved transport facilities and the increased accessibility of towns like London and Corbin. In general, these opportunities are not the kind that lead to the stabilization of agriculture in the area; they are casual, or they tend to serve as a substitute for, rather than as a supplement to, farming. It is principally by the encouragement of local industries genuinely supplementary to farming from the standpoint both of the products utilized and the employment of the farmers' time that an economy indigenous to the area can be developed. Such a development requires cooperative effort.

Consider first opportunities for saving through cooperative purchase of farm supplies, particularly seed, feed, and fertilizer. Between March 1, 1927, and March 1, 1928, in-shipments by railroad freight to London and East Bernstadt of seed (including potatoes), feed, and fertilizer, amounted to 11,073,709 pounds or the equivalent of 276.8 carloads of 40,000 pounds each. This would be at the rate of approximately 1 carload each of five week days and one-third of a carload on each Saturday throughout the year, or 5.32 carloads a week. During the period covered by the figures, shipments of seed were received every month, the heaviest receipts coming in February and continuing well into June. The volume again rose in September and October for fall seeding and then declined to the lowest point for the year in November, with relatively small receipts in December and January.

Some hay was shipped in, although this crop occupies a large proportion of the crop acreage. In-shipments of hay by rail amounted to 292 tons. The heaviest receipts were in December, January, and February, reaching a peak for the year in February. Shipments of hay declined when stock began to go on spring pasturage. No

receipts of hay at either point were recorded for April, July, and November during the period.

In-shipments of corn, on the other hand, were reported for every month in the year, the volume of shipments following, in general, the same seasonal variation as hay. The total volume of corn shipped in, amounting to 7,719 bushels, appears small. But allowing an average of 9 acres in corn per farm and an average yield of 20 bushels per acre, the total yield on the 203 farms for which data were summarized would amount to only 36,540 bushels. In-shipments, therefore, amounted on this basis to more than 20 per cent of the total production on these farms. In-shipments of oats amounted to 36,544 bushels, or nearly five times the amount of the production on the 203 farms. In addition to these feeds, 2,279 tons of concentrates were also shipped in. Other important items include receipts of considerable quantities of fertilizer and lime. These data amply demonstrate that there is a local market for home-grown feeds of good quality. But there are few farms that produce a surplus.

There is no present basis for supposing that local dealers are not providing efficient service to farmers in supplying these items and in providing the necessary credit. But there are undoubtedly opportunities for farmers to cooperate with local dealers by concentrating orders, pooling shipments, cooperative delivery, and similar means to reduce the cost and increase the effectiveness of this service.

There is a rather definite opportunity for farmers to cooperate on the producing and selling side. The possibility of developing cooperative methods for the production and sale of farm wood-lot products has been suggested. Mine props comprise the largest volume of shipments at present. The principal market is Lynch, Ky. Allowing 80,000 pounds to the carload, approximately 68.8 carloads were shipped during the year. Shipments were made every month, the largest volume occurring in October. Stave bolts were shipped to Cincinnati, Ohio. Some tanbark and a small quantity of pulpwood were shipped, and a few carloads of cordwood. The development of a local organization among farmers to assure volume and quality at low cost should be of help in maintaining and expanding the markets for these products.

Tobacco is the chief, and practically the only, cash crop. The principal market is Richmond, Ky. In 1927–28 freight shipments to this point from London and East Bernstadt amounted to 304,792 pounds. Truck shipments probably account for an equal or a larger volume. The bulk of the shipments were made in December and January, but small quantities were shipped in the two succeeding months. Cream is an important source of cash income. Shipments go to Cincinnati, Knoxville, Lexington, and Louisville. Some shipments are made direct by parcel post or as baggage, but an increasing proportion is delivered by farmers to London, East Bernstadt, and other points where it is purchased by local buyers for large manufacturers of dairy products. Competition among local buyers has tended to assure good prices to farmers, but the development of better facilities for delivery through cooperative organization among groups of farmers would materially improve the quality of the cream and tend to assure better average prices.

Farmers derive considerable income from the sale of poultry and eggs. The principal buyer of these products is a wholesale firm located

in Cincinnati which maintains a branch under a local manager in London. Here again it is probable that private agencies are providing a reasonably efficient selling service, but cooperative or community organizations for culling, grading, assembling, and delivering should increase the net returns to farmers.

Cattle are shipped out in considerable volume, and in the spring two or three carloads of hogs are shipped. Cattle shipments are usually made by enterprising local dealers who go from farm to farm making purchases until a carload can be shipped out. The months of heavy shipments are August and November. The principal market is Richmond, Ky. On account of scarcity of feed, Laurel County is not adapted to livestock production, but there is an opportunity for a few favorably situated farmers to make a fair return from this enterprise by organizing for cooperative shipments of livestock by rail, or truck to Richmond or other local concentration points.

The present volume of output of farm and forest products from Laurel County farms is too small, even in the aggregate, to attract privately owned and operated local creameries, cheese factories, woodworking plants, and similar enterprises for the utilization of the local production and the employment of local labor. The introduction and support of such enterprises is of doubtful feasibility and must depend, in any event, upon cooperative effort.

SCHOOLS

The grade school training of most children in Laurel County is still limited to the facilities of the 1-room school. Consolidation of schools is impracticable in many districts because of the difficulty of providing for the transport of children over the poor roads. Under present conditions children frequently travel to school on mules or on horseback.

The school census of Laurel County of April 1, 1928, gave 6,510 children between 6 and 18 years of age. Of this number, 2,866 boys and 2,743 girls were reported as enrolled in public elementary schools, 153 boys and 181 girls as enrolled in public high schools, and 62 boys and 110 girls as enrolled in private high schools. The annual report of the superintendent of the Laurel County schools for the school year ended June 30, 1928, reported about "100 high-school pupils in other high schools, for which we pay tuition." There were 86 wooden school buildings for white students: Seventy were 1-teacher schools, 13 were 2-teacher schools, and 3 had three or more teachers. There were 107 classrooms, or 1.24 rooms per school, and 108 teachers, including principals. The school term was seven months. The total number of elementary pupils enrolled was 4,498, and the average attendance was 3,318. This would give an average enrollment of 52.3 and an average attendance of 38.6 pupils per school, while the averages per room would be 42 and 31 pupils, respectively. The average aggregate seating capacity was 32.7 pupils per room, or 998 short of the total enrollment. Only 30 of the 86 schools were reported as having libraries.

The average annual salary paid white elementary teachers was $564.33. Thirty-seven per cent of the elementary teachers were men. There was no graduate of a standard college among the 108 elementary teachers. Only 5 teachers, 2 men and 3 women, had completed two

years of college work. Teachers with no high-school work included 7 men and 6 women, and 40 teachers, including 19 men and 21 women, had only two years of high-school work as their foundation for teaching. Nearly one-fourth of the teachers were teaching their first term, and approximately 50 per cent had taught less than three years.

The total school revenue of Laurel County in 1926–27 was $76,469.31, (*12, p. 362*) of which 52.4 per cent came from the State school fund, 39.2 per cent from local taxation, 8.1 per cent from loans and bonds, and 0.3 per cent from other sources. The total sum from these sources was augmented by a balance of $2,108.99, giving a grand total of $78,578.30, of which $78,444.91 was spent during the school year. County school funds derived from local taxation are based on a rate of 75 cents on each $100 of real and personal property and a poll tax of $1.

If the total amount available ($78,578.30) were distributed equally among the 88 schools (including two elementary schools for colored children) there would be available approximately $892.94 for each school. The figure sufficiently explains the low average annual salary of all county teachers (elementary and high school) and the inadequate training of the teachers. Transportation at public expense was not privided for any of these schools. In Kentucky, State school funds are so apportioned as to make it possible for counties that have relatively small tax resources to receive a greater amount of money per school child than do more wealthy counties. A continuance and extension of this policy should result in a considerable betterment of the school opportunities of the children of Laurel and other counties in eastern Kentucky.

CONCLUSIONS AND RECOMMENDATIONS

The central objective of the study was to differentiate the land in Laurel County farms on the basis of its important physical characteristics and then to relate differences in land character to important economic and social factors affecting family and community welfare. The relationships exhibited by the study provide the basis for a number of recommendations directly applicable to Laurel County and applicable, in principle, to localities in other counties where conditions are essentially similar.

BASIC CONDITIONS

Figure 7 shows the principal physical characteristics of 3,151 acres of crop and pasture land in 52 farms in Laurel County. Operators of these 52 farms had, over a 3-year period, an average, in round numbers, of 40 acres of crop land and 20 acres of pasture land per farm. The description of this crop and pasture land shown in Figure 7 indicates the importance to farmers in Laurel County of the kind, as well as the amount, of land in the individual farm.

The general effect of the physical characteristics of this land is to limit the amount of crop land, both because of the scarcity of land adapted to that use and because of the rapid deterioration of the land due to wrong cropping practices.

The combined effect of physical characteristics of the land and of cropping practices associated with the use of land (fig. 8) has been to establish a cycle in the utilization of fields. (Fig. 5.) The cycle

runs: Clearing, cropping, pasturing, abandonment; reclearing, cropping, etc. The exact sequence is subject to variation. The cycle is not characteristic of all fields or of the farm economy on all farms, but it is the most significant general characteristic of farming in Laurel County, and it is the central factor in the land utilization problems of that area. A summary of the consequences of this method of field utilization appears on pages 38 and 39 for crops and on pages 44 to 46 for pastures.

In 1924 approximately 30 per cent of the land in farms in Laurel County was woodland. (Table 2.) Unquestionably the development of profitable methods of management and utilization of farm

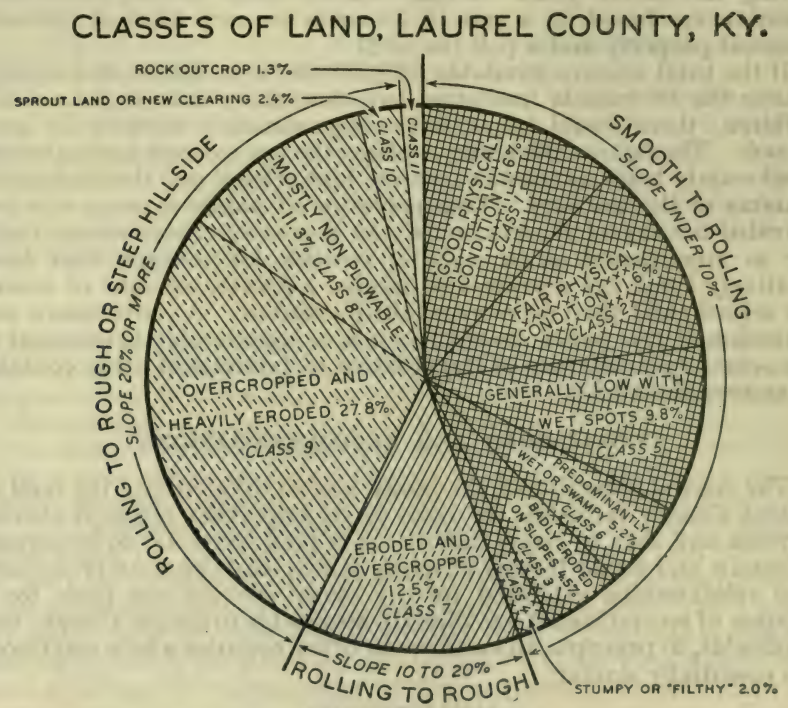

FIGURE 7.—Physical description of the crop and pasture land in 52 farms, Laurel County, Ky., 1928

wood lots would facilitate the introduction of improved practices in the utilization of land for crops and pastures and would, therefore, do much to correct the present practice on many farms of rotating fields in a wasteful cycle of reclamation, ruin, and abandonment. The conclusions as to the present relation of farm wood lots to the farm economy suggested by a study of sample plots on 49 farms are summarized on pages 56 to 59.

Obviously, the basic conditions suggested by Figures 7 and 8 and the conclusions reached with respect to present methods of utilizing land for crops, pasture, and timber, present a number of problems of considerable import to the future of agriculture in Laurel County and to the welfare of the population.

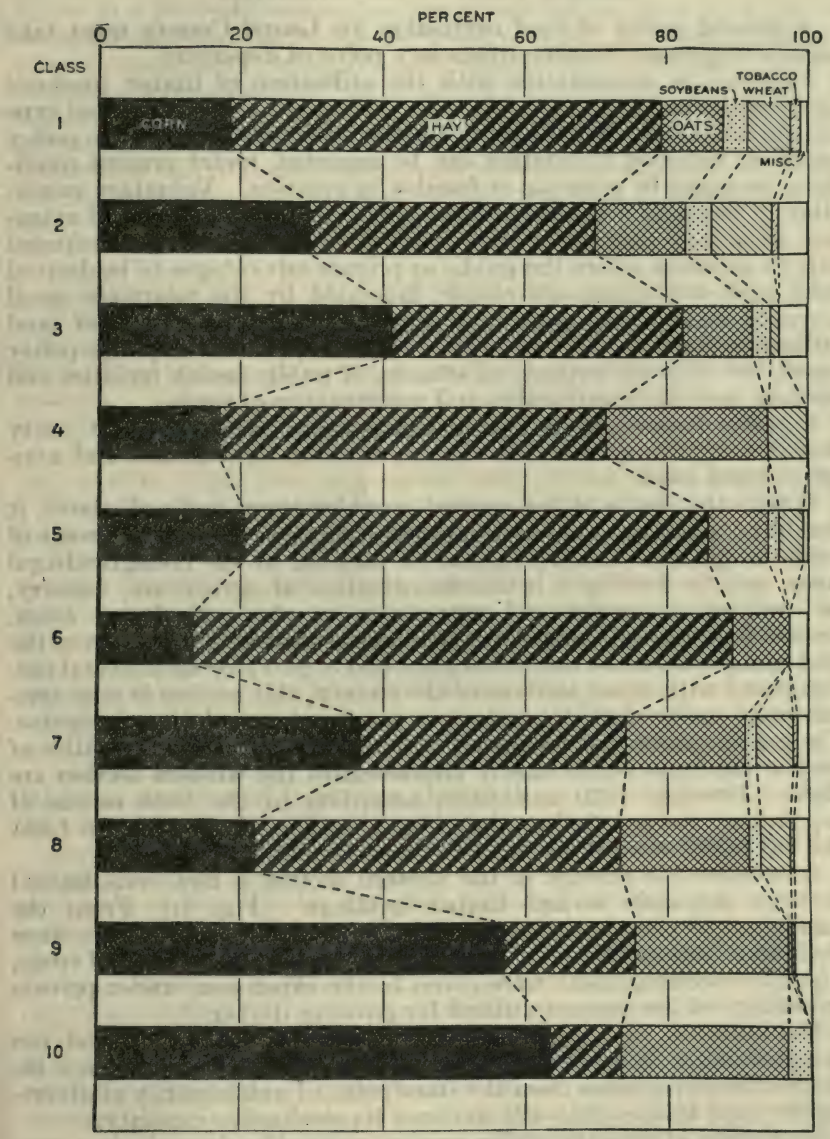

FIGURE 8.—PERCENTAGE OF CROP ACREAGE IN EACH LAND CLASS

The tendency to grow hay on the level or wet land is illustrated by the proportion of the acreage occupied by that crop on land in classes 1, 5, and 6. As land of moderate slope deteriorates through exhaustion of soil fertility by erosion and cropping a larger proportion of the acreage goes into corn. (Classes 2 and 3.) The effect of cropping land of intermediate slope to corn is illustrated by the condition of land in class 7. (Fig. 7.) Classes 8 and 9 offer a significant contrast in the condition of rough or steep land principally used for growing hay (class 8) and that of land of similar type (class 9) principally used for growing corn. (Fig. 7.) New clearings on steep land (class 10) are used principally for growing corn, whereas a large proportion of the partly reclaimed smooth to rolling land (class 4) is in hay.

RECOMMENDATIONS

GENERAL POLICY OF LAND UTILIZATION

A general policy of land utilization for Laurel County must take certain important considerations as a point of departure.

Farming, in combination with the utilization of timber products from farm wood lots, probably will continue to be the principal type of land utilization in the county for the indefinite future. No policy based on enforced evacuation can be regarded, under present conditions, as sound in principle or feasible in practice. Voluntary evacuation of farms as a condition prerequisite to the conversion of extensive areas from farming to forestry uses, obviously can be anticipated only in localities where the public or private advantages to be derived from such conversion are clearly indicated by the relatively small acreages under cultivation, and similar factors. A policy of land utilization can not be divorced from broader questions of public policy associated with the support of schools, of public health facilities and services, and the construction and maintenance of roads.

A policy directed to the future utilization of land in Laurel County should recognize a broad distinction between agricultural and nonagricultural areas.

Within the limits of the general considerations outlined above, it should be regarded as sound policy to encourage the development of public or private forestry instead of farming in the nonagricultural areas, and to develop a better coordination of agriculture, forestry, and related industries and enterprises in the agricultural areas. Broken topography, steep slopes, and light soils unfit a large part of the land in the western section (districts 4 and 5, pl. 1) for agricultural use. Compared with other sections of the county, this section is now agriculturally undeveloped, roads are poor and population is sparse. The present study has indicated that the agricultural possibilities of land of the type which chiefly characterizes the western section are slight. Between 1920 and 1930, according to the 1930 census of population, the population of district 4 declined from 1,744 to 1,661 and the population of district 5 declined from 3,260 to 1,828.

A considerable acreage in the western section is now consolidated in large privately owned timber holdings. (Fig. 1.) From the standpoint of private economy it would be of great advantage, since the land in this section is generally unadapted to the growing of crops, if public encouragement were given to the expansion, under private ownership, of the acreage utilized for growing timber.

Furthermore, the deterioration of the land in agricultural use operates in the long run to reduce the taxable basis, and hence increases the importance from the standpoint of public policy of diverting the land to uses that will conserve its productive capacity.

Expansion of forestry under private ownership depends to a considerable degree upon the application of principles of forest taxation that will encourage methods of management necessary to the proper development, adequate protection, and economical utilization of stands.

Although much of the land in agricultural use in other sections of Laurel County is physically unadapted to that use, these sections must, in view of the general considerations outlined above, be regarded as agricultural. Once this general conclusion is accepted the more

specialized questions of land utilization in Laurel County emerge. In the northern, central, and eastern sections, the determinative factor in a land-utilization program is the central place that farming occupies and, it must be assumed, will continue to occupy, in determining methods of using the land and modes of living. In these sections more especially, therefore, attention must be directed to adjustments in farm, forest, family, and public economy, involving primarily, not changes in the major use of land, but major changes in methods of use. The adjustments suggested are arranged under four headings to serve as a summary of the principal conclusions of the study.

ADJUSTMENTS IN FARM ECONOMY

Special attention should be given to obtaining a combination of land of the proper types in the individual farm.

Many farms in the north and south areas embrace land so poorly adapted to farming as to make profitable operation difficult or impossible. In general, it appears to be true that operators of farms with less than 45 acres of land suitable for crops, except those located on the Lee formation, whether in the north or the south area, must rely on work off the farm for a considerable portion of the farm income.

The type of land available for crops is more important than the mere aggregate of the crop acreage.

The smaller the acreage of crop land, the greater the proportion of it that must be of gentle slope, relatively free from erosion, and in good tilth (class 1) or land not too wet to produce good crops of hay and fair crops of corn (class 5). If less than 30 per cent of the crop land available is of the type falling in classes 1 or 5, or in these two classes combined, if the land with slopes of 20 per cent and over comprised in the crop acreage is not of the type falling in class 8, the land may rather safely be regarded as unadapted to farming.

An expansion of the crop acreage in a farm should not be undertaken as a means of increasing the total net returns from the farm, unless the land in the farm is of the proper type.

Farms located on the Lee formation and on the less rugged portions of the Breathitt formation usually embrace an adequate acreage of land of types suitable for cropping, although drainage would greatly increase the productive capacity of much of this land. Most farms on the Corbin conglomerate are under the double handicap of poor soil and poor drainage in securing an adequate acreage of land adapted to cropping. Operators of farms embracing a considerable extent of hillside crop land on the more rugged portions of the Breathitt formation can not successfully control erosion on the slopes, unless a considerable proportion of ridge land of gentle slope is included in the acreage. Some operators now maintaining a fairly large crop acreage, much of it on steep, heavily eroded, overcropped land, would do better to spend all or a major part of their time in other employment, utilizing the farm principally as a residence and garden. Some farms, with small crop acreages but favorable land characteristics, would justify an expansion of the crop acreage sufficient to employ all or a major part of the time of the operator. The practice of growing intensive crops such as tobacco, potatoes, and other truck, on small acreages of good land should be substituted for the practice of expanding the acreage to include poor land in the production of less intensive crops.

The establishment of long-lay pastures on the hillsides would permit an expansion in the dairy enterprise on many farms which, in combination with poultry, would absorb family and operators' labor to much better advantage than would the growing of corn on the hillsides.

Opportunities for operators to find part-time employment in occupations supplementary to farming or in other occupations should be expanded.

The data of the study indicate that where opportunities for outside employment exist a small farm and little or no farming is better than a slightly larger farm and relatively more farming. As a means of increasing income, expansion of opportunities for work off the farm is much more practicable than expansion of the crop acreage on farms which sometimes have not an acre and often have not an additional acre suitable for cultivation. In the south area opportunities for employment off the farm in occupations generally unrelated to farming are more extensive than in the less accessible north area.

In the less accessible areas, incomes of farmers may be increased by promoting cooperative organization along limited lines. Improvements in the harvesting and marketing of the products of the farm wood lot provide an opportunity for expanding employment supplementary to farming. The establishment of local cooperative plants for processing dairy products does not appear to be feasible. Until opportunities for supplementary employment are expanded, operators of many farms must continue to find it difficult to earn an adequate living. Coal mining provides part-time employment to a limited number of the operators of marginal farms, but there is no present prospect of an increase in the employment provided by local mines.

There are, however, a number of lines of cooperative endeavor which would tend to improve their methods of farming and to increase farm incomes.

Operators of farms, particularly in the less accessible localities, should take full advantage of all opportunities for effecting economies through cooperative organization along limited lines. Potential opportunities of this type include: (1) Cooperative purchase of farm supplies, particularly seed, feed, and fertilizer or lime; (2) cooperative delivery (and possibly sale or shipment) of cream; (3) cooperative culling of poultry flocks and cooperative grading, assembling, and delivering of poultry and eggs; and (4) cooperative shipment of livestock by rail or truck to local concentration points.

Better methods of farm organization and management should be encouraged as a means of effecting significant improvements in conditions on many farms. *(9)*

Of central importance in improved farm management practice is the more general adoption of effective and economical means of increasing crop yields. Soil experiments carried on in Laurel County since 1916 by the Kentucky Agricultural Experiment Station show that the use of agricultural limestone, phosphate, legumes, animal manure, and sods are the chief factors in securing larger yields on Laurel County farms. The more general use of legumes is essential for soil maintenance. Clovers require special soil treatment, except on recently cleared land. The soil experiments and the experience of local farmers who have applied the knowledge gained from these experiments show that the use of limestone and phosphate assures a good stand of clover. The experience of local farmers has also demonstrated that thin, unproductive crop land can be brought into good

condition by soil treatment, the growing of legumes and other feed crops, the feeding of these to livestock, and the application of the manure to the land.

A larger place in the farm organization should be given to intensive crops like tobacco, potatoes, and truck, and more intensive methods should be employed in the production of all crops grown. Growing intensive crops and using more intensive methods in crop production are equivalent to an increase in the amount and quality of crop land, and there is no greater economic need in the farming of the county than more good crop land. This need is a factor on practically all farms, but it is especially evident on a large number of farms which without the use of intensive enterprises are too small to provide adequate productive employment for the available farm labor. Since land suitable for cultivation is so scarce, it is imperative that efficient use be made of every acre of tillable land. A smaller acreage will then provide an adequate family living, and thus reduce the acreage of steep land which many operators who use less intensive crops and methods feel compelled to cultivate.

Since much of the land of this area is rolling or steep, the proper utilization of the land in any system of cropping must provide a sod cover for the land most of the time. It follows that grass and roughage-eating livestock are necessary to an efficient farm economy. Laurel County is in a deficit feed area and prices of both grain and roughage feeds are high. Livestock, to be profitable, must be limited as a rule to the kinds and numbers that can be carried on home-grown grass and roughage supplemented by limited quantities of purchased concentrates.

Because of the small size of most of the farms and the relatively large amount of family labor to be employed, dairy cattle fill the most important place as a livestock enterprise. Beef cattle and sheep offer an economic means for utilizing grass and hay land when labor, markets, or other requisites of dairying are not available.

Hogs do not fit well into a plan of farm organization in Laurel County and have no place as a farm enterprise, except to provide meat for the family and possibly a small quantity of fresh pork for sale locally. Poultry are more profitable users of home-produced grain and dairy by-products than are hogs.

Special attention should be given to the production of a supply of home-grown food products ample for the family needs.

Vegetables, fruits, and dairy and poultry products can be provided by most farmers in quantities adequate for the family table. Although it is true that more than this is required in order for a farm to provide an adequate living, yet improvements to be achieved in this way are applicable to so many farms and are of such immediate practicability as to justify placing the increased production of home-grown foods for family use as a first step in securing a better adjustment of the economy on many farms.

ADJUSTMENTS IN FOREST ECONOMY

The central objective should be to manage and operate the farm wood lot as an integral part of the farm economy.

The essential adjustments include: (1) Restriction of the farm wood lot to a size that can be efficiently managed and economically utilized

as a part of the farm economy and, as a corollary; (2) consolidation of numerous small, poorly managed, and inefficiently utilized tracts into large, efficiently managed forest reserves; [26] (3) management and utilization of the farm wood lot as a farm enterprise, with a view to obtaining the full benefit of its complementary and supplementary relationships to other farm enterprises, and to securing from it a regular annual income as from other enterprises of the farm.

Lumbering, sale of farm wood-lot products, and the development of wood-using industries offer the most practicable means of supplementing income from farming, particularly among operators of farms in the less accessible localities.

Any considerable expansion in employment in lumbering is contingent on the development of stands in large units, to permit large-scale operations; the development of an organization among farmers for the cooperative production and marketing of farm wood-lot products, such as mine props, ties, staves, and poles, would tend to stabilize and increase the income derived from these sources; successful developments along the lines suggested would tend to provide a basis for the successful operation of a local woodworking establishment.

ADJUSTMENTS IN POPULATION

A decrease in the pressure of population appears to be essential to the solution of major economic problems.

Economically, pressure of population has led to attempts to utilize for the production of crops, land that is wholly unadapted to that purpose. The result has been to place many families on a subsistence economy, the economic basis of which tends to decrease with progressive deterioration of the land; socially, the depletion of the economic basis of life has undermined the stability and security of many families and caused frequent moves from farm to farm in an effort to obtain a livelihood; culturally, the development of a subsistence economy behind geographic barriers has retarded and tends to impede the infiltration of external social and economic influences; psychologically, social and cultural isolation has habituated the individual to a mode of life that is not easily adjusted to the requirements of industrial or commercial occupations.

Educational effort should be directed to adjusting the social and cultural environment of the family to changes in the economic environment.

Economic forces have so changed the requirements for successful farming that some families are under strong economic pressure to leave the mountains. Social forces, on the other hand, operating through the family, create in the individual strong emotional attachments which operate against migration. Nethertheless, migration from the mountains is taking place, particularly from areas in which external contacts have been facilitated by improved means of travel and communication. There is evidence that migration from the more isolated areas will increase as such facilities improve. Improvements in housing, selection and preparation of foods, care of farm gardens,

[26] The limited forest tract assessment and yield tax law of Kentucky (6) has been held unconstitutional by the attorney general. A State forest tax law designed to permit and encourage, under proper regulations, the consolidation under cooperative ownership, management, and utilization of wooded areas now in farms, but which can not practicably be utilized as farm wood lots, would provide a helpful basis for improving farm-forest economy.

sanitation, hygiene, child care, and similar factors relating to standards and conditions of living can be achieved by many families simply by utilizing the resources at hand. Extension instruction and demonstration would be of great practical benefit. The type of adjustments in farm and forest economy suggested as desirable are, however, fundamental to the development of a more adequate basis of family living and the conditions of a more wholesome family life. These developments would tend to adjust population to resources, both by a better distribution of population within the area, and by better utilization of the land. The most practicable means of accelerating the adjustment of population to resources are the improvement and expansion in educational opportunities and in means of travel and communication.

ADJUSTMENTS IN PUBLIC POLICY

Four important phases of public policy are inseparably involved in other adjustments suggested. A policy of liberal State support to developments along the following four lines should not only accelerate the progress of adjustment, but serve to ameliorate conditions while adjustments are being effected.

(1) Roads: The significance of a few good roads in the agricultural areas will not end with the transportation of persons and goods, but will facilitate adjustments and improvements through the communication of ideas. A policy designed to provide good roads in areas adapted to farming would encourage the proper utilization of the land and enhance the returns to be obtained from it.

(2) Schools: Adequate educational facilities and competent instruction are of fundamental importance, particularly as a means of facilitating the adjustment of population to resources. Better roads would greatly simplify the problem of better schools. Improvements in the location, construction, and facilities of schools would be feasible under the proposed plan of adjustments. A reduction in the number of schools and an increase in the capacity would facilitate improvements in the quality of the instruction. In Kentucky, State school funds are apportioned so as to make it possible for counties having relatively small tax resources to receive a greater amount of money per school child than more wealthy counties. A continuance and extension of this equalization policy should result in a considerable betterment of the educational opportunities of the children of Laurel and other counties in eastern Kentucky.

(3) Forests: The importance of a good forest tax law was noted above.

(4) Credit: It should be an important feature of public policy to develop or make available to farmers adequate credit facilities, including facilities for financing such cooperative enterprises as may contribute to the economical operation of the mountain farm.

LITERATURE CITED

(1) Burke, R. T. Avon, Bennett, F., and Lounsbury, C.
1912. soil survey of rockcastle county, kentucky. U. S. Dept. Agr., Bur. Soils Field Oper. 1910, Rpt. 12 : 1017–1048, illus.

(2) Campbell, M. R.
1898. london folio, kentucky. U. S. Geol. Survey Folio 47, [15] p., illus.

(3) DAVIS, D. H.
1924. THE GEOGRAPHY OF THE MOUNTAINS OF EASTERN KENTUCKY; A RECONNAISSANCE STUDY OF THE DISTRIBUTION AND ACTIVITIES OF MAN IN THAT PART OF THE CUMBERLAND PLATEAU EMBRACED BY THE COMMONWEALTH. 180 p., illus. Frankfort, Ky. (Ky. Geol. Survey, ser. 6, [Geol. Rpt.] no. 18.)

(4) HOLMES, J. S., and HALL, R. C.
1909. STUDY OF FOREST CONDITIONS IN KENTUCKY: Ky. Bur. Agr., Labor, and Statis. Bien. Rpt. (1908/9) 18 : [5]–178.

(5) JONES, S. C.
1913. SOILS OF THE EASTERN COAL FIELDS. Ky. Geol. Survey (4) 1 (pt. 2): 1067–1078.

(6) KENTUCKY LAWS, STATUTES, ETC.
1926. ACTS OF GENERAL ASSEMBLY OF THE STATE OF KENTUCKY. CH. 9, AN ACT PROVIDING FOR THE ESTABLISHMENT AND MAINTENANCE OF FOREST RESERVES; DEFINING FOREST RESERVES; PROVIDING FOR THE LISTING, RECORDING, WITHDRAWAL, USE, TRANSFER OF TITLE, ADMINISTRATION AND TAXATION OF FOREST RESERVES; ESTABLISHING A FOREST RESERVE FUND; PROVIDING FOR THE CUTTING OF TIMBER ON FOREST RESERVES, FOR CHANGES IN THE PROVISIONS OF THIS ACT AND A PENALTY FOR THE VIOLATION OF THE PROVISIONS OF THIS ACT. Kentucky Laws, Statutes, etc. 1926: 22–31.

(7) KENTUCKY STATE DEPARTMENT OF MINES.
1925–1928. ANNUAL REPORTS.

(8) MILLER, A. McQ.
1919. THE GEOLOGY OF KENTUCKY; A CLASSIFIED COMPEND OF STATE REPORTS AND OTHER PUBLICATIONS, WITH CRITICAL COMMENT BASED ON ORIGINAL INVESTIGATIONS. Ky. Univ., Dept. Geol. and Forestry, ser. 5, Bul. 2, 392 p., illus.

(9) NICHOLLS, W. D., and HAWTHORNE, H. W.
1930. FARM MANAGEMENT AND INCOMES OF FARM FAMILIES IN LAUREL COUNTY, KENTUCKY. Ky. Agr. Expt. Sta. Bul. 305, p. 219–283, illus.

(10) ODLAND, T. E., WILSON, C. V., HENDERSON, H. O., and DEATRICK, E. P.
1930. PASTURE EXPERIMENTS. W. Va. Agr. Expt. Sta. Bul. 235, 32 p., illus.

(11) OYLER, M.
1930. COST OF LIVING AND POPULATION TRENDS IN LAUREL COUNTY, KENTUCKY. Ky. Agr. Expt. Sta. Bul. 301, p. 65–90, illus.

(12) RHOADS, McH.
[1927]. BIENNIAL REPORT OF THE SUPERINTENDENT OF PUBLIC INSTRUCTION OF THE STATE OF KENTUCKY FOR THE TWO YEARS ENDING JUNE 30, 1927. 421 p. [Frankfort, Ky.]

(13) SEILLER, E. F. (compiler).
n. d. KENTUCKY NATURAL RESOURCES, INDUSTRIAL STATISTICS, INDUSTRIAL DIRECTORY, DESCRIPTION BY COUNTIES. Ky. Bur. Agr., Labor and Statis. Bul. 34, 389 p., illus.

(14) UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE.
1927. AMERICAN FORESTS AND FOREST PRODUCTS. U. S. Dept. Agr. Statis. Bul. 21, 324 p.

(15) ———, WEATHER BUREAU.
1926. SUMMARY OF THE CLIMATOLOGICAL DATA FOR THE UNITED STATES, BY SECTIONS. U. S. Dept. Agr., Weather Bur. Bul. W., Ed. 2, v. 3.

(16) UNITED STATES DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS.
1927. UNITED STATES CENSUS OF AGRICULTURE, 1925. 3 v., illus. Washington, [D. C.]

(17) VERHOEFF, M.
1911. THE KENTUCKY MOUNTAINS, TRANSPORTATION AND COMMERCE, 1750 TO 1911; A STUDY IN THE ECONOMIC HISTORY OF A COAL FIELD 208 p., Louisville. (Filson Club Pub. 26.)

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FARM-MORTGAGE CREDIT

BY

DAVID L. WICKENS

Agricultural Economist, Division of Agricultural Finance
Bureau of Agricultural Economics

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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WASHINGTON, D. C.

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By DAVID L. WICKENS
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INTRODUCTION

Dominance of farm mortgages as a source of farm credit results naturally from the fact that three-fourths of the farmers' property consists of land and buildings. During the last 20 years farmers

[1] Credit is due to Carrie W. Strawbridge for supervising the handling of schedules and for work on the extensive computations and to Marguerite Foy Golden for assistance in the preparation of tables and other materials.

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have greatly increased their use of credit secured by real estate, largely because of higher price levels, increased cost of farm equipment, and the funding of debt accumulated in other forms. This expanded use of long-term credit has been aided by improved lending facilities, notably the Federal farm-loan system, and by more favorable mortgage interest rates in many sections. The inducement of lower cost as well as the distressed condition of many banks incident to the price decline following the World War prompted numerous transfers of short-term credit to long-term farm mortgages.

Taken all together, the farmers' fixed obligations have acquired volume and importance greater than ever before. The total farm-mortgage debt, which in 1910 represented less than 10 per cent of the value of all farm real estate, in 1928 amounted to 21 per cent.

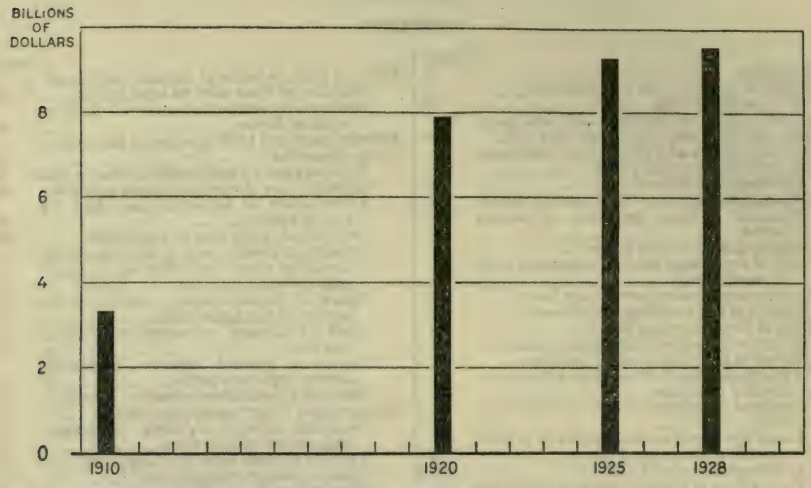

FIGURE 1.—TOTAL FARM-MORTGAGE DEBT, JANUARY 1, 1910, 1920, 1925, AND 1928

The total farm-mortgage debt of the United States increased from $3,320,470,000 January 1, 1910, to $9,468,526,000 in 1928. Most of this increase occurred between 1910 and 1920 when the debt rose 136 per cent, compared with a further increase of 19 per cent between 1920 and 1925, and 1 per cent from 1925 to 1928.

This increased volume of farm mortgages acquired especial significance with the reversal of the general price trend in 1920. For a long period prior to that date a ready supply of funds was looked upon as a favorable factor, aiding the purchase and equipment of farms and the attainment of more profitable production combinations of land, labor, and capital in developing the agricultural areas.

Following the marked turn in the price trend in 1920, the favorable view of the farm mortgage has given way to a more discriminating attitude toward borrowing. The fixed obligations of many farms have become heavy items of expense, and rates of return on the invested capital often have been less than rates on the borrowed capital. By 1925, the mortgage debt had become 19 per cent of the value of all farm real estate, but the outlay for interest on this debt was equal to about one-third of the net return from farm real estate and equal to about one-half of the net return on the equity of all such real estate.

Recent mortgage experience shows the necessity for centering more attention on long-term aspects of farm finance. Events of the last two decades have indicated that borrowing and loaning policies based on short-term considerations have been inadequate for meeting the problems involved. Changes in price level have become increasingly important as prices have receded from their position in 1920. After the change in price trend the volume of mortgage debt continued to increase for eight years, thus causing further disparity between income and expenditures for interest and principal. In view of the fact that the average mortgaged farm remains under mortgage usually from 25 to 35 years or longer, the owner of such property becomes subject to all the consequences which the changes of a generation may bring about.

This bulletin aims to present the facts concerning farm mortgages as they have developed during recent years and then to suggest various methods by which the farmer can so manage his long-term financing as to make adjustment to problems that are likely to be encountered over a period of years.

The war years and the decade following have brought a train of significant developments in farm-mortgage finance. During those years loans secured by farm land and buildings increased in both volume and numbers in the United States up to 1928. Beginning with a farm mortgage debt of $3,320,470,000 in 1910, a steady rise in the following decade, with special stimulus in the war years, amounted to an increase of 136 per cent and an estimated total debt of $7,857,700,000 in 1920. The debt was further increased to $9,360,620,000 on January 1, 1925, or 19 per cent above 1920. Three years later estimates indicated an additional increase of only about 1 per cent, with a total debt of $9,468,526,000 on January 1, 1928. (Fig 1 and Table 1.)

TABLE 1.—*Total farm mortgage debt*[1] *and percentage changes by geographic divisions and States January 1, 1910, 1920, 1925, and 1928*

State and geographic division	Farm mortgage debt, Jan. 1—				Percentage changes					
					1910–1920		1920–1925		1925–1928	
	1910	1920	1925	1928	Increase	Decrease	Increase	Decrease	Increase	Decrease
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Maine	13,210	20,890	26,097	25,252	58.1		24.9			3.2
New Hampshire	5,870	8,600	7,732	7,780	46.5			10.1	0.6	
Vermont	15,850	29,040	28,001	28,322	83.2			3.6	1.1	
Massachusetts	22,890	34,180	32,207	31,262	49.3			5.8		2.9
Rhode Island	2,210	2,350	2,435	2,455	6.3		3.6		.8	
Connecticut	16,080	25,800	27,276	27,423	60.4		5.7		.5	
New England	76,110	120,860	123,748	122,494	58.8		2.4			1.0
New York	154,190	224,060	226,776	219,812	45.3		1.2			3.1
New Jersey	31,720	39,500	41,741	40,370	24.5		5.7			3.3
Pennsylvania	95,620	133,080	120,281	116,432	39.2			9.6		3.2
Middle Atlantic	281,530	396,640	388,798	376,614	40.9			2.0		3.1
Ohio	113,320	210,760	214,409	222,101	86.0		1.7		3.6	
Indiana	111,280	206,600	264,483	277,269	85.7		28.0		4.8	
Illinois	266,780	502,850	650,353	685,365	88.5		29.3		5.4	

[1] In addition to the farm-mortgage debt as reported by the Census, the estimated farm-mortgage debt on other farms has been added.

TABLE 1.—*Total farm mortgage debt and percentage changes by geographic divisions and States January 1, 1910, 1920, 1925, and 1928*—Continued

State and geographic division	Farm mortgage debt, Jan. 1—				Percentage changes					
					1910–1920		1920–1925		1925–1928	
	1910	1920	1925	1928	Increase	Decrease	Increase	Decrease	Increase	Decrease
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Michigan	109,970	215,740	228,089	235,399	96.2		5.7		3.2	
Wisconsin	193,600	455,470	504,553	529,992	135.3		10.8		5.0	
East North Central	794,950	1,591,420	1,861,887	1,950,126	100.2		17.0		4.7	
Minnesota	146,160	455,540	553,784	558,458	211.7		21.6		.8	
Iowa	431,500	1,098,970	1,424,352	1,402,178	154.7		29.6			1.6
Missouri	202,650	385,790	449,022	447,351	90.4		16.4			.4
North Dakota	101,450	267,780	226,714	230,250	164.0			15.3	1.6	
South Dakota	88,700	278,880	372,004	370,946	214.4		33.4			.3
Nebraska	161,850	416,860	617,930	599,418	157.6		48.2			3.0
Kansas	163,770	295,870	482,596	447,586	80.7		63.1			7.3
West North Central	1,296,080	3,199,690	4,126,402	4,056,187	146.9		29.0			1.7
Delaware	6,500	8,990	8,695	9,469	38.3			3.3	8.9	
Maryland	29,580	49,230	50,422	54,980	66.4		2.4		9.0	
District of Columbia	290	340	304	354	17.2			10.6	16.4	
Virginia	24,000	61,600	79,709	87,117	156.7		29.4		9.3	
West Virginia	8,210	15,960	18,570	20,155	94.4		16.4		8.5	
North Carolina	18,960	56,580	78,606	90,866	198.4		38.9		15.6	
South Carolina	20,530	51,220	68,735	77,214	149.5		34.2		12.3	
Georgia	28,800	83,840	109,060	123,305	191.1		30.1		13.1	
Florida	4,380	19,710	25,508	28,436	350.0		29.4		11.5	
South Atlantic	141,250	347,470	439,609	491,896	146.0		26.5		11.9	
Kentucky	40,510	104,100	94,549	103,798	157.0			9.2	9.8	
Tennessee	26,850	83,130	85,857	96,711	209.6		3.3		12.6	
Alabama	24,880	55,450	66,410	69,488	122.9		19.8		4.6	
Mississippi	31,320	77,420	109,562	111,500	147.2		41.5		1.8	
East South Central	123,560	320,100	356,378	381,497	159.1		11.3		7.0	
Arkansas	22,200	76,870	97,809	103,464	246.3		27.2		5.8	
Louisiana	19,090	41,250	57,910	61,760	116.1		40.4		6.6	
Oklahoma	77,680	188,890	218,963	228,513	143.2		15.9		4.4	
Texas	172,240	396,670	485,587	507,515	130.3		22.4		4.5	
West South Central	291,210	703,680	860,269	901,252	141.6		22.3		4.8	
Montana	19,620	154,940	116,616	104,862	689.7			24.7		10.1
Idaho	24,270	115,350	107,355	100,033	375.3			6.9		6.8
Wyoming	7,820	32,970	43,364	40,922	321.6		31.5			5.6
Colorado	41,800	138,400	153,727	144,464	231.1		11.1			6.0
New Mexico	4,810	23,670	28,784	26,900	392.1		21.6			6.5
Arizona	4,880	31,790	29,545	29,006	551.4			7.1		1.8
Utah	7,170	35,550	39,152	36,367	395.8		10.1			7.1
Nevada	3,340	11,880	15,244	13,997	255.7		28.3			8.2
Mountain	113,710	544,550	533,787	496,551	378.9			2.0		7.0
Washington	45,040	116,740	121,371	120,523	159.2		4.0			.7
Oregon	34,950	91,090	105,503	110,875	160.6		15.8		5.1	
California	122,080	425,460	442,868	460,511	248.5		4.1		4.0	
Pacific	202,070	633,290	669,742	691,909	213.4		5.8		3.3	
United States	3,320,470	7,857,700	9,360,620	9,468,526	136.6		19.1		1.2	

Table 1 indicates the total farm-mortgage debt for each of the States and geographic divisions for each of the four dates for which data are available and the percentage changes between those dates. In the decade 1910 to 1920 the increase in debt on farm real estate was shared by every State to some extent, and in the Mountain division

there was a notable rise of nearly 380 per cent over 1910. The 5-year period 1920 to 1925 continued the increase in total debt for 38 States, the West North Central division rising 29 per cent above 1920. The relatively slight increase in the country as a whole during the 3-year period 1925 to 1928 suggested that the prolonged rise in amount of farm mortgages was approaching a turning point. Further evidence of this tendency appeared in the definite decline in the amount of mortgages held by several principal lending agencies during 1928 and 1929.

The great increase in long-term agricultural credit during this period was brought about by a number of factors, but chiefly by higher prices for land. The average value of farm land in the United States rose from $39.60 per acre in 1910 to $69.38 in 1920. Larger indebtedness per farm became the natural consequence of higher prices whenever a mortgage was used in settling land purchases, a practice employed in most land sales. Larger numbers of transfers stimulated by rising prices increased the number of mortgages which reflected the higher values.

Shifting of credit from the form of short-term loans already made to the form of farm mortgages constituted a major part of the post-war adjustment of the farmer's finances. As late as 1923 commercial banks reported that 55 per cent of their farm-mortgage loans were made for the purpose of paying other debts.[2] Meanwhile, the banks were steadily removing mortgages from their portfolios by encouraging farmers to transfer their land-secured loans to specialized mortgage agencies. The net result of this latter movement was a decline in the volume of mortgages held by commercial banks from $1,447,500,000 on January 1, 1921, to about $1,020,000,000 in 1928.

Following 1920 and the passing of greatest activity in farm transfers, the volume of farm-mortgage debt was further enlarged by the unfavorable balance of income and expense which bore heavily on the farmer in the immediate postwar years. A sharp decline in the prices of farm products to levels much below prices of other commodities, together with increased costs from taxes and labor, led many farmers to use mortgage loans to meet current expense.

Compared with 1913 as 100, the farmers' outlay for taxes rose continuously to 263 in 1928 (*18*).[3] Farm wages, after the drop in 1921–22, rose to a level in 1928 that was 69 per cent above pre-war amounts (*18*). Meanwhile, the farmer has expended greatly increased amounts for farm machinery and equipment in his effort to reduce cost of production. In all parts of the country farmers reporting in 1928 on the causes of debt frequently mention expense for the purchase of machinery as a contributing factor. (Table 42.)

A further element has been the increased outlay for automobiles on farms, even during the postwar depression. Available data indicate that the number of motor vehicles on farms increased from over 3,100,000 in 1922 to about 4,900,000 in 1929 (*14*).

After 1920 the volume of debt secured by real estate was further enlarged by the process of refunding short-term indebtedness incurred during the war years or through the following period of rapidly

[2] This and other figures in text not found in tables or readily derived therefrom and not attributed to named sources are derived from investigations by the Division of Agricultural Finance, Bureau of Agricultural Economics.

[3] Italic numbers in parentheses refer to Literature Cited, p. 100.

falling prices, a process best indicated by the farm-credit operations of commercial banks.

The personal and collateral loans made by banks to farmers were estimated at $3,870,000,000 on December 31, 1920 (*28*). Three years later it was slightly less than $3,000,000,000 (*15*). This reduction, averaging more than $270,000,000 a year, compares with an average annual increase in the total amount of farm mortgages of more than $300,000,000 during the five years from the beginning of 1920 to the beginning of 1925. Doubtless much of this short-term bank credit was liquidated by the sale of crops and livestock and by the completion of other operations for which the advances had been made. The funding process was utilized much more, however, during the immediate postwar years than later because of the efforts of banks to provide or strengthen security on loans made when prices were high.

Important among the causes of the recent reductions in loan operations has been a smaller demand for credit. Whereas much of the rapid increase in farm mortgages in the years prior to 1920 arose out of transfers of land at high prices, more recently, and especially since 1925, land transfers have been much less frequent, lower prices have resulted in smaller considerations and in smaller new farm mortgages. Prices for articles which farmers have had to buy have slowly declined. Completion of most of the fundings of war-time obligations reduced the importance of that cause of mortgages, and a more conservative attitude of lenders in making new loans and renewals has operated to reduce the volume of outstanding farm-mortgage indebtedness.

Throughout the post-war years, including the period 1925 to 1928, the number of farms mortgaged increased for the country as a whole and for most of the principal divisions, thus continuing the upward trend of the last 40 years. Tenant-operated farms showed a greater increase in the percentage mortgaged than did owner-operated farms. Data regarding both transferred and nontransferred farms indicate a larger number of farms carrying mortgages in 1928 than in 1925, and transferred farms report larger amounts per farm as well. The ratio of debt to value of mortgaged farms averaged 41.9 per cent on owner-operated farms in 1925 and 46 per cent in 1928, although the average amount of debt per farm mortgaged was slightly less in 1928 than in 1925. This increase in the average ratio of debt to current value of farms mortgaged was partly due to increased debt, but was principally the result of the declining value of land.

One of the most significant developments since 1920 has been the change in relative importance among the principal sources of farm-mortgage credit. In general this change has taken the form of shifting of loans out of the hands of former owners, other individuals, and commercial banks into the possession of larger and more centralized agencies. In 1920 commercial banks were the largest source of such credit, having 18.4 per cent of all such loans. By 1928 banks had declined to third place with 10.8 per cent of the total, life-insurance companies had risen to first rank with 22.9 per cent, the Federal land banks had 12.1 per cent, and the joint-stock land banks had 7 per cent of the total mortgage debt. (Table 8.)

The natural tendency toward decline in loan volume, which was induced by lower land values and completion of funding, received a further impetus in 1928 and 1929 from rising interest rates on the

central money markets. During the latter part of 1928 and especially during 1929, higher rates and higher bond yields restricted the flow of funds into long-term loans of all kinds. These higher rates, by cutting off the supply of funds to the Federal and joint-stock land banks which operate under legal interest rate limitations, and by offering more attractive outlets for funds of other lenders, probably restricted the volume of new mortgages to a smaller total than would otherwise have been true.

After nearly two years of rising interest rates, during which period rates on farm mortgages also rose, the break in the stock market in October and November, 1929, brought the beginning of a period of lower interest rates on central money markets. Although the effect of this change was slow to show itself on farm loans in common with other long-term borrowings, both the availability and cost of farm-mortgage credit became more favorable to farmers during 1930.

The farm-mortgage experience of the country thus far has brought into relief a number of problems to which attention must be given if the most advantageous handling of the farmer's long-term credit requirements is to be secured. These questions include not only favorable terms and items concerned with the original negotiation of loans, but also a consideration of the problem of carrying the loan and of repaying it. In the principal agricultural areas interest rates quoted by local sources are commonly the most expensive. Moreover, because of the necessity of relieving local stress by funding of short-term loans, there is a tendency for the volume of new mortgages to be largest at those times when rates are higher than usual. The term for which most loans are contracted is found to have little or no relation to the period for which indebtedness remains on the farm. The comparative brevity of the average term of loans made under these circumstances has its sequel in the hazards and uncertainties of refinancing when temporary disruptions in the money market may imperil the chances of securing an adequate loan on reasonable terms.

The long period that typically ensues before the mortgaged farm is cleared of debt calls for greater consideration of methods of repayment and more attention to price level than have generally been given. The relation of credit cost to the rate of return from the land mortgaged requires careful planning early in the life of the loan if the danger of foreclosure is to be avoided.

Farmers do not have the alternative method of financing possessed by some other lines of business. In conducting the large annual amount of agricultural financing a farmer must remain aware of these limitations and so, whenever possible, choose such methods as will most nearly accomplish his purpose without loss of title to the property.

METHODS OF ESTIMATE AND COMPUTATION

The total farm-mortgage debt of the United States has been determinable only by means of estimating the debt on land of certain tenures. The census reports of 1890, 1910, 1920, and 1925 gave the indebtedness of farms entirely owned by their operators. Although these reports included over half of the total farms, they omitted the debt on tenant-operated farms, manager-operated farms, and part-owner farms, that is, those partly owned and partly rented. For these farms estimates have been necessary.

Methods used in arriving at a total figure for mortgage debt have begun with use of the amount for full-owner farms reported by the United States census for the year in question or the nearest date for which census data were available. The debt carried by farms of other tenures has been computed by applying to their census values ratios assumed to be the same as for owner farms, or ratios indicated by sample studies of such farms of other tenure. Inasmuch as the available data concerning debt on farms of other tenure have varied in extent during the periods since estimates were first made, the methods used have caused some differences in the results.

The first official estimate, published in 1916 for the year 1910, assumed that farms of all tenures had the same ratio of debt to value as farms operated by their owners. The total debt of $3,598,985,000 originally estimated for that year was obtained by—

assuming that the ratio between the mortgage debt on farms operated by their owners and the total value of all such farms holds good for tenant farms also. It is possible that this ratio may be too high for the tenant farms in some of the States, in which case the estimates will be too large; but even if this is the case, the figures presented have considerable value as representing the maximum amount of farm mortgages probably outstanding in the census year (*16, p. 9, footnote 1.*)

As late as 1920 no data were available to indicate any difference in debt on farms of different tenures. Accordingly an estimate of total farm-mortgage debt for 1920 employed the same method as that used for the year 1910.

The figures for estimated total farm mortgage indebtedness * * * are based on the assumption that in each State all farms are on the average mortgaged to the same percentage of their value as are the owner-operated farms for which data are available. This is a somewhat bold assumption, as no comprehensive study has been made of the relative amount of indebtedness on owner-operated farms as compared with that on farms of other tenures. It seems probable that these figures are somewhat high for many States, or, in other words, that they represent the maximum rather than the actual amount (*27, p. 2*).

Debt calculations for 1920 and earlier underestimated the encumbrance on part-owner farms by failing to allow for the greater percentage of such farms under mortgage, amounting in 1925 to 42 per cent more than for full-owner farms. It was not until 1925, however, that the census made available data on the relative acreage of owned and rented land in these part-owner farms, thus permitting allowance for greater debt on the owned part. In the absence of data on the ratio of debt to value of part-owner farms the estimates for 1925 and 1928 assumed this ratio to be the same as for full-owner farms. Some understatement probably results on this account. When data become available on the amount of debt on this class of farms they are likely to reveal higher debt ratios than occur on full-owner farms, though the difference probably is less than for the percentage of farms mortgaged. A high correlation usually occurs between frequency and debt ratio.

An inquiry addressed to farm owners in 1922 showed that, in 1920, mortgage debt on owner farms amounted to 13.3 per cent of the value of all such farms, while mortgage on tenant farms was only 9.2 per cent of the value of all tenant farms. A new estimate of total farm-mortgage debt for 1920 was made by Leon E. Truesdell and V. N. Valgren in which this lower ratio was applied to tenant-operated farms. Manager farms and part-owner farms were considered as

having the same ratio as full-owner farms. The result was a total substantially below the first estimate for 1920. Later a new estimate for 1910 was made by applying to the census data for owners of that year a proportion for tenants indicated by the inquiry for 1920. The detailed figures of this estimate, used here for the first time, were considerably less than in the original estimate for 1910 (*9*).

It is possible that this method still leaves the estimated debt on tenant farms in 1910 too high. The closeness of the tenant and owner ratios in 1925 and 1928 when compared with the difference between 13.3 and 9.2 in 1920 suggests that the divergence may have been greater before 1920.

Estimates of indebtedness of manager-operated farms for 1910 and 1920 assumed that such farms had the same ratio of debt to value as owner farms. Manager farms average much larger than do farms of any other class. Large farms are mortgaged in more than the average number of cases, but carry debt bearing a lower-than-average ratio to the farm values. The net result as indicated by the 1925-1928 studies suggests that treatment of manager farms on the basis of owner farms, as done in previous estimates, probably gave results slightly too high for manager farms. The assumption of debt ratios equal to those of owner farms is particularly unwarranted for the North Atlantic States where many farms of this class are not operated for profit.

Estimated debt supplementing full-owner debt in 1910 and 1920 was distributed as proportionate parts of totals for the geographic divisions, whereas estimates for owners in 1928 were made for individual States in all but a few instances, and estimates for tenant farms were made by States for the divisions having most of the mortgage debt.

DIFFERENCES IN CENSUSES

Computations in the estimates for 1925 and 1928 were aligned with the 1925 census data on value of land, percentage of farms mortgaged, and ratio of debt to value as reported for full-owner farms. Any understatement or overstatement as shown in that census, therefore, will be reflected in the estimates of total debt for 1925 and 1928. Doubtless some understatement results from incomplete reporting and failure to ask for the existence of the debt separate from the amount. The 1920 census schedule carried a question asking whether the farm was mortgaged and another question asking the amount of the mortgage (*19*). The number of full-owner farms reporting the amount of mortgage in that year was 1,193,047, or 24,187 less than the total reported number of mortgaged farms operated by their owners. This is a 2 per cent difference. In addition, 9.9 per cent of owner-operated farms gave no report on mortgage whatever. Inasmuch as the 1925 census asked only the amount of mortgage on the farm, the number of farms that had mortgages in 1925 but did not report either the fact or the amount is not known. This fact probably has resulted in an underestimate for 1925 and 1928, especially in some areas.

Any reluctance of farmers about reporting the debt on their farms probably is more likely to appear if the debt is large. The doubling of the mortgage debt between 1910 and 1920 may have contributed to the unusually high percentage of "unknown" farms in that year as compared with earlier census reports. The further increase of

farm-mortgage debt between 1920 and 1925 may be assumed also to have continued any bias due to this reason. In view of the large number of "unknown" farms in the Southern States as shown by the 1920 census, any bias on account of this class of farms is likely to be pronounced for that region.

Notwithstanding the approximations and inexactness which must occur in any statement based on other than complete data, the estimates for 1925 and 1928 seem to have a fair degree of accuracy as indicated by Table 2.

TABLE 2.—*Percentage of error in 1928 national estimates of farm-mortgage debt*

Lending agency	Holdings indicated by reporting farms (weighted)		Actual holdings		Difference between estimate and actual holdings	
	Ratio to total holdings	Amount	Ratio to total holdings	Amount	Amount	Error
	Per cent	*1,000 dollars*	*Per cent*	*1,000 dollars*	*1,000 dollars*	*Per cent*
Federal land banks	12.17047	1,152,364	12.10783	1,146,433	5,931	0.52
Jointstock land banks	6.94752	657,828	7.04770	667,314	−9,486	−1.42
Insurance companies	23.60598	2,235,138	22.85683	2,164,205	70,933	3.28
Total		4,045,330		3,977,952	67,378	1.69

METHODS USED IN ESTIMATING TOTAL FARM-MORTGAGE DEBT AS OF JANUARY 1, 1925 AND 1928

The estimates of total farm-mortgage debt for January 1, 1925 and 1928, using the 1925 census as a base, were made principally from data received from farmers, bankers, and county recorders. The farmers' reports were used in estimating the debt on farms under the same ownership from 1925 to 1928, and reports from bankers and county recorders in one-fourth of the agricultural counties were used in estimating the debt in 1928 on farms transferred between the years 1925 and 1928.

Data from farmers were obtained by means of questionnaires sent to all farm owners, except part owners, in 85 counties in 47 States. The counties were selected for representative type of production and geographic location, a number being selected so that they might represent areas in each of two or more adjoining States. The data used were taken from 22,352 replies representing farms that had changed neither ownership nor tenure during the period 1925–1928. These schedules reported value of farm December 31, 1924, and amount of mortgage debt December 31, 1924 and 1927, the holder of the mortgage on December 31, 1927, and the interest rate on each loan. Although all data represent status as of December 31, 1924 and 1927, the dates January 1, 1925 and 1928, are used to maintain comparability with census usage and with practice in previous debt estimates.

Values as of census date as given on returned schedules but reported three and one-half years later were checked with values for the same farms reported to the census. This comparison for over 6,000 owner farms from 11 counties showed only 1 per cent difference from the census values for the same farms. Accuracy of reports on tenant-

operated farms was supported by comparison with census returns for owner farms in the same areas, and with 38,800 unpublished reports of debt on tenant farms obtained by the Bureau of the Census.

The following ratios were computed for each type of tenure and for each State for both 1925 and 1928, first using for each State only those counties which lay within that State's borders: (1) Percentage of all farms mortgaged; (2) percentage of reported debt, to December 31, 1924, value of mortgaged farms; and (3) percentage of reported debt to value of all farms including those not mortgaged.

Similar ratios were computed for 25 States on the basis of data which included reports from adjoining or neighboring counties of contiguous States. In those instances in which the results of these second groupings gave ratios more closely reflective of the situation for the State, as indicated by comparison with census ratios for owner-operated farms, they were used in the subsequent computations.

The data obtained from farmers' reports were aligned with the results of the 1925 census by use of a correction factor, found by dividing the ratio of debt to value of all full-owner farms by a similar ratio computed from census data for the same State or geographic division.

This correction factor derived from data on full-owner farms was applied to ratios of debt to value obtained in the sample for other tenures on the assumption that whatever bias appeared in the returns from owners was also true of reports for farms of other tenure in the same State or geographic division. This factor was used on the sample data save in those instances in which the sample permitted use of the data in a proportion, thus making the correction directly on an individual State basis. In computing all geographic-division figures the various State figures were weighted by the value of land in the State and the sum of the products was divided by the sum of the value of land in the geographic division to obtain the weighted geographic-division figure.

The debt on farms fully owned by their operators in 1925 was taken as reported in the 1925 census. The value of the owned part of part-owner farms was computed on the assumption that the owned value was proportionate to the owned acreage. The debt on part-owner farms was computed by multiplying the computed value of the owned part of such farms by the ratio of debt to value of all full-owner farms and multiplying this result by the percentage of mortgages among part-owner farms divided by the percentage of full-owner farms mortgaged. These percentages were derived from census data.

Debt on tenant-operated farms for 1925 was estimated by use of the equation $\frac{a}{b}=\frac{A}{X}$ in which

a = the ratio of debt to value of all full-owner farms reporting on schedules (1925).

b = the ratio of debt to value of all tenant farms reporting on schedules (1925).

A = the ratio of debt to value of all full-owner farms as per the 1925 census.

X = the computed ratio of debt to value of all tenant-operated land in any given State or division.

The resulting ratio, represented in the equation by X, was applied to the value of all tenant-operated land including that of the rented part of part-owner farms.

Computation of debt for full-owner farms in 1928 was made by States, save the New England States, and by individual States for tenant farms in the East and West North Central States.

Debt on owner farms in New England States in 1928 was found by distributing the computed debt of the geographic division among the respective States on the basis of the percentage which the full-owner debt of each State had of the total debt on full-owner farms of the geographic division as shown by the 1925 census.

All debt on manager farms was first computed on the basis of weighted ratios representing the following five groups, subsequent allocation to each division being made on the basis of relative value of land of that tenure: (1) New England (data from New England plus New York counties); (2) Middle Atlantic; (3) South Atlantic, East South Central, West South Central; (4) East North Central and West North Central; (5) Mountain and Pacific. The estimates for the last four groups were made on the basis of the second groupings of counties.

Debt computations for tenant-operated farms in States other than the North Central group were made first on the basis of geographic divisions. Debt computations for manager farms in all States were made from the ratios found for the five geographic divisions or combinations of geographic divisions as described above, the ratio being applied to the value of tenant-operated land or manager-operated land in the division to obtain the geographic-division debt. In the case of both tenants and managers the final allocation of the geographic total was made for each State by means of the following equation:

$$\Sigma\left[\frac{\frac{a}{b}c}{\left(\frac{a}{b}c\right)+\left(\frac{a'}{b'}c'\right)+\frac{a''}{b''}c''\cdots}\right]d=e$$

in which

a = debt on full-owner farms in a given State in 1925.
b = value of full-owner farms in the same State in 1925.
c = value of all tenant (or manager) land in the same State in 1925.
d = estimated debt for all tenant (or manager) land in the geographic division in 1925.
e = estimated debt on tenant (or manager) land in State in 1925.
a' b' c', a'', b'', c'' = corresponding debt and values in other States of the same geographic division.
Σ = sum of all States in the geographic division.

The debt for 1928 was found by applying ratio relatives as percentages of the debt already found for the particular State or division and tenure as of 1925. These ratio relatives were computed by dividing the ratio of 1928 debt to the 1925 value of all farms by the ratio of 1925 debt to the 1925 value of all farms and checked by the relative for the geographic division, the trend of debt for other tenures in the same area, and changes in outstanding loans in the State as reported by the known sources of the Federal land banks, the joint-stock land

banks, and national banks. The resulting relative or percentage of the 1925 ratio was applied to the amount of debt already found for 1925 to compute the debt for 1928.

Relatives for individual States were used for both owner and tenant farms, save for Wyoming, Nevada, and the New England States; for individual States for tenant farms, save for New England, the Middle Atlantic, and South Atlantic divisions, in which cases the relative for the geographic division was used as having greater probable accuracy. The relative for Maryland was used for the District of Columbia.

For 1928, relatives for manager farms were used as computed from the weighted ratios of the five divisional groups cited above.

Debt in 1928 on farms changing ownership from 1925 to 1928 was computed from reports of 642 bankers and recorders in agricultural counties distributed over the United States. These bankers and recorders reported for their counties their estimates of: (*a*) The percentage of farms changing hands during the period; (*b*) the percentage of these transferred farms that were mortgaged at the beginning and the percentage that were mortgaged at the end of the 3-year period; and (*c*) the ratio of debt to value of these mortgaged farms as of the two above dates. The difference between the products of these three percentages ($a \times b \times c$) and ($a \times b' \times c'$) for each geographic division as of respective dates represented the estimated increase or decrease in debt on transferred farms expressed as a percentage of the 1925 value of all land and buildings in such geographic divisions. The amounts represented by the resulting increases in seven geographic divisions and decreases in the other two were distributed among the States on the basis of 1925 full-owner debt and among the five types of tenure on the basis of their respective percentages of the total geographic divisional debt estimated for 1925.[4]

PRINCIPAL FEATURES AND CHANGES IN FARM-MORTGAGE INDEBTEDNESS SINCE 1910

GEOGRAPHICAL DIFFERENCES

The geographical distribution of the volume of farm-mortgage debt has maintained a general similarity since 1910. As a whole, this distribution indicates a general correspondence with the value of farms in the various sections of the country and, consequently, shows a bulk of such credit in the upper Mississippi Valley. Of the total debt in 1928, over 63 per cent is found in the 12 North Central States, the West North Central division having a farm-mortgage debt of $4,056,000,000, or 42.8 per cent of the total, and the East North Central, $1,950,000,000, or 20.6 per cent of the total. Next in importance in volume of debt is the West South Central division with 9.5 per cent of the total, and the Pacific States with 7.3 per cent; other areas have about 5 per cent or less. Although the relative importance of most of the areas has remained about the same through two decades, the Middle Atlantic and New England divisions had only about one-half the proportionate amount of the total debt in 1928 that they held in 1910, and the Mountain and Pacific States had substantial

[4] Other discussions on method appear in appropriate sections.

increases in their proportions of the total from 1910 to 1920. (Fig. 2 and Table 3.)

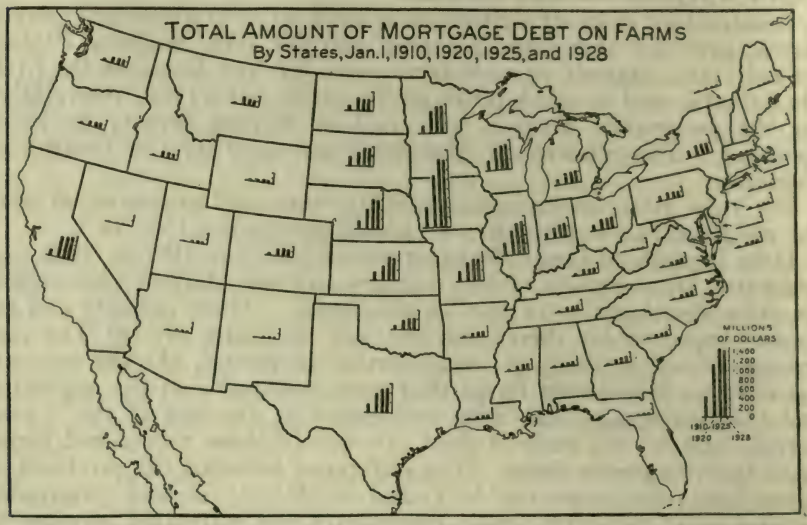

FIGURE 2.—The principal volume of farm-mortgage debt is found in States of the Mississippi Valley and north of the Ohio River, with substantial amounts in California and Texas. The East North Central division had 20.6 per cent of the total in 1928, the West North Central 42.8 per cent, and Iowa alone had 14.8 per cent of the total mortgage debt of the country. The South and the Mountain States have the smallest parts of the total. A general correspondence between debt and land value is apparent

TABLE 3.—*Percentage distribution of total mortgage debt in the United States, by States and geographic divisions, 1910–1928*

State and geographic division	Percentage of debt in each State and geographic division to total debt in the United States				State and geographic division	Percentage of debt in each State and geographic division to total debt in the United States			
	1910	1920	1925	1928		1910	1920	1925	1928
	Per cent	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*
Maine	0.40	0.27	0.28	0.27	South Dakota	2.67	3.55	3.97	3.92
New Hampshire	.18	.11	.08	.08	Nebraska	4.87	5.30	6.60	6.33
Vermont	.48	.37	.30	.30	Kansas	4.93	3.76	5.15	4.73
Massachusetts	.69	.43	.34	.33					
Rhode Island	.06	.03	.03	.02	West North Central	39.03	40.72	44.08	42.84
Connecticut	.48	.33	.29	.29					
					Delaware	.20	.12	.09	.10
New England	2.29	1.54	1.32	1.29	Maryland	.89	.63	.54	.58
					District of Columbia	.008	.004	.003	.003
New York	4.64	2.85	2.42	2.32	Virginia	.72	.78	.85	.92
New Jersey	.96	.50	.45	.43	West Virginia	.25	.20	.20	.21
Pennsylvania	2.88	1.70	1.28	1.23	North Carolina	.57	.72	.84	.96
					South Carolina	.62	.65	.74	.82
Middle Atlantic	8.48	5.05	4.15	3.98	Georgia	.87	1.07	1.17	1.30
					Florida	.13	.25	.27	.30
Ohio	3.41	2.68	2.29	2.34					
Indiana	3.35	2.63	2.82	2.93	South Atlantic	4.25	4.42	4.70	5.19
Illinois	8.04	6.40	6.95	7.24					
Michigan	3.31	2.74	2.44	2.49	Kentucky	1.22	1.32	1.01	1.10
Wisconsin	5.83	5.80	5.39	5.60	Tennessee	.81	1.06	.92	1.02
					Alabama	.75	.71	.71	.73
East North Central	23.94	20.25	19.89	20.60	Mississippi	.94	.98	1.17	1.18
					East South Central	3.72	4.07	3.81	4.03
Minnesota	4.40	5.80	5.92	5.90					
Iowa	13.00	13.99	15.22	14.81	Arkansas	.67	.98	1.04	1.09
Missouri	6.10	4.91	4.80	4.72	Louisiana	.87	.53	.62	.65
North Dakota	3.06	3.41	2.42	2.43					

TABLE 3.—*Percentage distribution of total mortgage debt in the United States, by States and geographic divisions, 1910–1928*—Continued

State and geographic division	Percentage of debt in each State and geographic division to total debt in the United States				State and geographic division	Percentage of debt in each State and geographic division to total debt in the United States			
	1910	1920	1925	1928		1910	1920	1925	1928
	Per cent	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*
Oklahoma	2.34	2.40	2.34	2.42	Utah	0.22	0.45	0.42	0.38
Texas	5.19	5.05	5.19	5.36	Nevada	.10	.15	.16	.15
West South Central	8.77	8.96	9.19	9.52	Mountain	3.43	6.93	5.70	5.24
Montana	.59	1.97	1.25	1.11	Washington	1.36	1.49	1.30	1.27
Idaho	.73	1.47	1.15	1.06	Oregon	1.05	1.16	1.13	1.17
Wyoming	.24	.42	.46	.43	California	3.68	5.41	4.73	4.87
Colorado	1.26	1.76	1.64	1.52	Pacific	6.09	8.06	7.16	7.31
New Mexico	.14	.30	.31	.28					
Arizona	.15	.41	.31	.31	United States	100.00	100.00	100.00	100.00

The largest relative increase in mortgage debt for the 3-year period ended January 1, 1928, was one of 12 per cent in the South Atlantic States. Debt in the East South Central division increased 7 per cent and in the Pacific division 3 per cent. Four geographic divisions showed declines in amount of farm-mortgage credit. Of these reductions the Mountain States had 7 per cent below 1925, the Middle Atlantic States 3 per cent, the West North Central 2 per cent, and New England 1 per cent. These decreases in debt contrast with the steady rise in the same areas during previous years. In general, the significant differences in the debt changes among geographic divisions consisted of increases in the Southern and East North Central States, whereas the western areas, save the Pacific division, had declines. (Table 1.)

MORTGAGE DEBT ON OWNER-OPERATED FARMS

The question of fixed indebtedness is of primary significance to farm owners who operate the land they own. Mainly because of the dominance of owner-operated land, farms operated by their owners have the most important part of all farm-mortgage debt. The debt on all owner farms in 1928 was $5,560,017,000, or 58.7 per cent of the total; debt on all tenant-operated land amounted to $3,644,009,000, or 38.5 per cent, and debt on farms operated by managers was only $264,500,000, or 2.8 per cent. (Table 4.) The greater interest of owner-operators becomes more apparent when the debt on tenant and manager farms owned by active farmers is considered. When these items are included, the active farmer is found to have approximately three-fourths of all land-secured debt.

TABLE 4.—*Estimated farm-mortgage debt in the United States, by tenure, 1920, 1925, and 1928* [1]

Year	Total farm-mortgage debt	Owner-operated farms		Tenant-operated farms		Manager-operated farms	
		Amount	Percentage of total	Amount	Percentage of total	Amount	Percentage of total
	1,000 dollars	*1,000 dollars*		*1,000 dollars*		*1,000 dollars*	
1920	7,857,700	5,314,150	67.7	2,185,480	27.8	350,070	4.5
1925	9,360,620	5,504,437	58.8	3,612,193	38.6	243,900	2.6
1928	9,468,526	5,560,017	58.7	3,644,009	38.5	264,500	2.8

[1] See also text p. 10 for differences in method of computation.

For the country as a whole, the increase in fixed debt between 1925 and 1928 occurred on farms of all forms of tenure, debt on owner-operated farms increasing about 1 per cent and on tenant-operated farms about 0.8 per cent. Within some individual geographic divisions, however, the indebtedness on one form of tenure increased whereas the debt on other tenure forms decreased. Largest increases of debt on farms operated by owners occurred in the South Central division; farms operated by tenants had their greatest rate of debt increase in the South Atlantic and Pacific States. (Table 5.) These estimates for 1928 assumed no change from 1925 in the relative importance of tenure classifications.

TABLE 5.—*Farm-mortgage debt in the United States, according to tenure of farm, by geographic divisions and States, January 1, 1925 and 1928*

State and geographic division	Total mortgage debt		Debt on owner-operated farms		Debt on tenant-operated farms		Debt on manager-operated farms	
	1925	1928	1925	1928	1925	1928	1925	1928
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
Maine	26,097	25,252	25,207	24,323	743	806	147	123
New Hampshire	7,732	7,780	7,357	7,393	296	321	79	66
Vermont	28,001	28,322	24,933	25,050	2,834	3,077	234	195
Massachusetts	32,207	31,262	29,595	28,696	1,538	1,670	1,074	896
Rhode Island	2,435	2,455	2,082	2,092	273	296	80	67
Connecticut	27,276	27,424	24,656	24,761	1,895	2,057	725	606
New England	123,748	122,494	113,830	112,315	7,579	8,227	2,339	1,952
New York	226,776	219,812	177,110	171,302	41,153	40,388	8,513	8,122
New Jersey	41,741	40,370	33,116	31,945	7,167	7,034	1,458	1,391
Pennsylvania	120,281	116,432	91,551	88,323	25,564	25,088	3,166	3,021
Middle Atlantic	388,798	376,614	301,777	291,570	73,884	72,510	13,137	12,534
Ohio	214,409	222,101	152,979	151,821	54,146	63,053	7,284	7,227
Indiana	264,483	277,269	148,383	152,664	109,175	117,734	6,925	6,871
Illinois	650,353	685,365	293,047	312,372	338,839	354,672	18,467	18,321
Michigan	228,089	235,399	169,263	174,783	50,670	52,524	8,156	8,091
Wisconsin	504,553	529,992	414,010	428,636	80,078	90,974	10,465	10,382
East North Central	1,861,887	1,950,126	1,177,682	1,220,276	632,908	678,957	51,297	50,893
Minnesota	553,784	558,458	326,561	334,925	222,930	219,472	4,293	4,061
Iowa	1,424,352	1,402,178	765,475	764,415	642,254	622,035	16,623	15,728
Missouri	449,022	447,351	268,564	272,753	174,867	169,308	5,591	5,290
North Dakota	226,714	230,250	134,326	136,570	89,996	91,417	2,392	2,263
South Dakota	372,004	370,946	177,858	175,541	190,695	192,140	3,451	3,265
Nebraska	617,930	599,418	320,628	303,437	291,263	290,267	6,039	5,714
Kansas	482,596	447,586	206,512	191,357	271,762	252,140	4,322	4,089
West North Central	4,126,402	4,056,187	2,199,924	2,178,998	1,883,767	1,836,779	42,711	40,410
Delaware	8,695	9,469	4,356	4,283	3,754	4,469	585	717
Maryland	50,422	54,980	30,141	30,656	15,085	17,959	5,196	6,365
District of Columbia	304	354	82	83	30	36	192	235
Virginia	79,709	87,117	59,114	62,439	15,974	19,017	4,621	5,661
West Virginia	18,570	20,155	14,582	15,377	3,105	3,696	883	1,082
North Carolina	78,606	90,866	47,427	53,699	29,821	35,503	1,358	1,664
South Carolina	68,735	77,214	34,416	36,286	32,287	38,439	2,032	2,489
Georgia	109,060	123,305	53,826	57,299	48,189	57,374	7,045	8,632
Florida	25,508	28,436	18,606	20,041	1,747	2,080	5,155	6,315
South Atlantic	439,609	491,896	262,550	280,163	149,992	178,573	27,067	33,160
Kentucky	94,549	103,798	71,006	79,583	22,828	23,378	715	837
Tennessee	85,857	96,711	59,274	69,382	25,863	26,486	720	843
Alabama	66,410	69,488	36,365	38,571	29,030	29,729	1,015	1,188
Mississippi	109,562	111,500	52,107	52,189	54,234	55,539	3,221	3,772
East South Central	356,378	381,497	218,752	239,725	131,955	135,132	5,671	6,640

TABLE 5.—*Farm-mortgage debt in the United States, according to tenure of farm, by geographic divisions and States, January 1, 1925 and 1928*—Continued

State and geographic division	Total mortgage debt		Debt on owner-operated farms		Debt on tenant-operated farms		Debt on manager-operated farms	
	1925	1928	1925	1928	1925	1928	1925	1928
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
Arkansas	97,809	103,464	51,726	56,982	43,004	42,887	3,079	3,595
Louisiana	57,910	61,760	33,062	36,337	21,080	21,023	3,768	4,400
Oklahoma	218,963	228,513	99,366	108,835	117,207	116,888	2,390	2,796
Texas	485,587	507,515	231,530	251,811	240,316	239,662	13,741	16,042
West South Central	860,269	901,252	415,684	453,965	421,607	420,460	22,978	26,827
Montana	116,616	104,862	69,654	60,588	44,678	41,652	2,284	2,622
Idaho	107,355	100,033	67,479	62,517	38,296	35,702	1,580	1,814
Wyoming	43,364	40,922	25,016	23,518	16,954	15,805	1,394	1,599
Colorado	153,727	144,464	82,209	77,078	68,214	63,594	3,304	3,792
New Mexico	28,784	26,900	16,754	15,388	10,651	9,929	1,379	1,583
Arizona	29,545	29,006	16,396	16,175	10,491	9,781	2,658	3,050
Utah	39,152	36,367	31,086	28,785	7,779	7,252	287	330
Nevada	15,244	13,997	11,371	10,067	2,393	2,231	1,480	1,699
Mountain	533,787	496,551	319,965	294,116	199,456	185,946	14,366	16,489
Washington	121,371	120,523	91,912	86,609	25,207	28,925	4,252	4,989
Oregon	105,503	110,875	82,036	83,856	19,988	22,937	3,479	4,082
California	442,868	460,511	320,325	318,424	65,850	75,563	56,693	66,524
Pacific	669,742	691,909	494,273	488,889	111,045	127,425	64,424	75,595
United States	9,360,620	9,468,526	5,504,437	5,560,017	3,612,193	3,644,009	243,990	264,500

INCREASES IN DEBT FREQUENCY ON TENANT FARMS

A comparison of changes in debt frequency on land of different tenure classification shows that the increase in number of tenant farms mortgaged between 1925 and 1928 was more pronounced than that of owner farms, the percentage of owner farms with debt having risen from 34 per cent to 34.7 per cent as compared with a rise from 32.5 per cent to 34.8 per cent for tenant farms. The same tendency for tenant-operated farms to increase the percentage mortgaged more rapidly than owner farms is shown in a comparison of mortgages contracted and mortgages paid off by the two tenures for the period 1925 to 1928. Owners clearing their farms of debt were 3.7 per cent of the total owner farmers reporting; tenant farms cleared of debt were only 3.1 per cent of the total of such farms reporting. Meanwhile, new farms mortgaged by owner operators were 4.1 per cent of all owner farms reporting, and tenant-operated farms mortgaged for the first time in the period amounted to 4.7 per cent of the total.

MORTGAGES ON TENANT FARMS

A comparison of individual mortgages as affected by the form of tenure of the land reveals the tenant-operated farm as having larger average indebtedness than does the owner-operated farm, although the ratio to value is lower. (Table 6.) Manager-operated farms, in turn, have still larger amounts of debt per farm, when mortgaged, than do farms of other tenures. This fact, due mainly to the relative size of farms in these groups, is significant in comparing the credit cost

for loans of various sizes, and in explaining why some lending agencies have a large proportion of their loans on tenant farms, and what the consequences are to agencies that confine their loans to farms operated by their owners.

TABLE 6.—*Average size of farm-mortgage loans outstanding,*[1] *loans obtained and loans paid,*[2] *by tenure and geographic divisions*

Geographic division and tenure	Average farm-mortgage loan outstanding, Jan. 1, 1928	Average farm-mortgage loan—		Geographic division and tenure	Average farm-mortgage loan outstanding, Jan. 1, 1928	Average farm-mortgage loan—	
		Obtained 1925 to 1928	Paid 1925 to 1928			Obtained 1925 to 1928	Paid 1925 to 1928
	Dollars	*Dollars*	*Dollars*		*Dollars*	*Dollars*	*Dollars*
New England	1,680	1,876	1,242	West South Central	4,051	3,393	2,782
Owners	1,643	1,757	1,235	Owners	3,001	3,529	1,874
Tenants	2,742	3,520	1,500	Tenants	5,054	3,254	3,720
Middle Atlantic	2,414	2,252	1,848	Mountain	4,403	3,618	2,775
Owners	2,191	2,064	1,820	Owners	3,660	3,050	2,348
Tenants	3,995	3,400	2,017	Tenants	6,078	4,414	3,533
East North Central	5,722	4,377	2,153	Pacific	6,423	8,541	4,731
Owners	4,462	3,067	1,784	Owners	4,943	5,363	2,450
Tenants	8,208	6,385	3,070	Tenants	11,919	17,782	14,655
West North Central	8,079	5,457	3,695	United States:			
Owners	6,254	4,851	2,813	All tenures	5,205	4,487	2,696
Tenants	10,089	6,139	4,559	Owners	3,919	3,552	2,061
South Atlantic	3,895	4,342	2,574	Tenants	7,780	5,884	4,404
Owners	3,149	4,419	2,613	Managers	13,576	15,581	10,875
Tenants	4,262	4,211	2,278				
East South Central	3,784	2,918	897				
Owners	3,062	2,194	876				
Tenants	4,722	4,456	967				

[1] Jan. 1, 1928. [2] 1925–1928.

SIZE OF MORTGAGES PAID OFF COMPARED WITH THOSE OBTAINED

Mortgages reported paid off during 1925–1928 were consistently smaller than were new mortgages incurred on other farms in the same divisions. (Table 6.) A total of 786 farms cleared of debt had mortgages averaging 25.7 per cent of the 1925 value of the farms, whereas 954 new mortgages averaged 28.8 per cent of the 1925 value of the farms. This tendency toward larger new mortgages appeared in all divisions. In the South Central division the size of new mortgages was smaller, although the number incurred was definitely greater than for the mortgages paid off.

Taken as a whole, the mortgage on many farms has been a definite burden during the last decade since prices have fallen while indebtedness has remained. In addition to rising land values before 1920 and the funding of other debt since that time, an important factor has been the increase due to the cost of existing debt.

Whenever the debt-to-value ratio of a farm mortgage exceeds the yield-cost ratio, the debt thereafter tends to increase in size and the ratio of debt to value tends to increase further, because the net income from the land each year is less than the interest payment required and, to that extent, represents an encroachment on the capital investment of the farm. It is probable that the number of farms that have added to their debt from this cause has been considerable.

MOVEMENT TOWARD LOWER DEBT LEVELS

The declines in farm-mortgage debt in certain States and divisions from 1920 to 1925 and from 1925 to 1928, indicate that, notwithstanding the increase in the total debt of the country, an underlying movement toward reduction was operating even before 1925. This movement appeared first in the Mountain States following the sharp recession in land values after 1920. Extensive foreclosures and reversion of title prior to 1925 contributed to the decline in debt shown by a number of States and to the slackened rate of increase elsewhere.

During the five years 1920–1925, two geographic divisions and 10 States registered reductions in their total mortgage debt on farms. The more important of these occcurred in Montana, North Dakota, Idaho, and Arizona, where widespread repossession by former owners and actual reductions in the number of farms were supplemented by smaller lending operations of important agencies.

Three years later declines had appeared in four of the nine geographic divisions and in 19 States. Thus, by 1928 the downward changes in the farm-mortgage debt of western areas had acquired a definite trend. The Mountain division and each of the constituent States showed declines. The West North Central division as a whole, and five of its seven States, indicated less debt on the land. Meanwhile, in the older section of the country slightly less encumbrance was indicated in each of the Middle Atlantic States and in two New England States. (Table 1.)

The marked change which became definitely apparent by 1925 doubtless had some relation to the expiration of many mortgages made in 1919 and 1920 for terms of five years or less. Much of this indebtedness originally contracted for production purposes was not liquidated within the prescribed term and had been transferred to the mortgage form. Large numbers of mortgages were held by individuals and commercial banks, the latter the largest holders of this class of securities in 1920. (Table 8.)

Nearly all the outstanding loans were for short terms of years. Of the loans held by banks in 1923, 52 per cent were for terms of one year or less, 20 per cent for terms of two to four years, and 27 per cent for five years. At the same date more than 82 per cent of the mortgages held by insurance companies had terms of five years or less. The termination of these periods was often followed by reductions in the amount granted on the renewal. (Table 33.)

COURSE OF THE MORTGAGE MOVEMENT

A consideration of the part played by lending institutions in relation to farm-mortgage-debt changes from 1910 to 1928 discloses the character of the fore part of a major mortgage movement in which the principal volume of indebtedness arises and the process by which the debt is first accumulated, then transferred, and then reduced.

Out of a period of generally rising commodity prices increased activity in land transfers develops. The steadily mounting scale of sale prices overshadows the significance of current income and causes its purchasing power to be neglected. Greater demands for funds, occasioned by higher prices accompanied by a tendency to expand investment in livestock and equipment, induce borrowers to apply

for larger loans. Lenders grant these loans on the assumption of continued higher prices. Sellers of farms are willing to take large proportions of the selling price in first or second mortgage, and buyers welcome the opportunity to acquire land with small down payments (*11*).

The local banks that stand closest to the farmer are the first of the institutions to encounter the demand for larger credits of all kinds. Likewise, as the most convenient financial agency for facilitating land transfers, the local banks frequently extend liberal credits on farm mortgages that run from one to five years. Of all financial agencies serving farmers, the local banks are most sensitive in reflecting changes in farmers' finances. The amount of mortgages held by banks rose moderately from 1914 to 1918, with a marked rise during the next two and one-half years.

When the upward trend of prices is reversed, the activity in land sales declines and purchase-money mortgages become infrequent. Many former owners and others who hold mortgages seek to transfer a part or all of their holdings to banks or agencies specializing in long-term loans. Some of this class of mortgage debt begins to disappear through foreclosure or surrender of title because of failure of buyers to make payments. Commercial banks seek to strengthen their position on unpaid balances due them by encouraging farmer borrowers to fund their short-term loans in land mortgages. Other accounts and funds for current working capital are likely to be included in the new loan. This often involves the use of second mortgages.

The general result is that for a period the mortgage holdings of the banks continue in considerable amount after their short-term loans to farmers have begun a marked decline. But as the volume of land-secured credit becomes a restriction on the bank's principal business of short-term lending, many of the land mortgages are shifted to other agencies that specialize in farm loans. The short term of most of these loans makes early refinancing necessary, and the transfer process may be hastened by the sale of the mortgage before the expiration of the term.

With the steady transfer of mortgages from the original holders to insurance companies, land banks, and other agencies, the total volume of their holdings continues to rise long after the holdings of individuals and banks have begun to decline. Finally when the refunding operations are largely completed and many of the loans made on high valuations become out of proportion to current prices, many mortgages are renewed for smaller amounts. Meanwhile as the price level falls and the purchasing power of money increases, new loans are made for smaller amounts. Other loans are renewed on condition that substantial payments are made with the result that the total volume of mortgages held by the long-term agencies declines. With this down turn in the volume of holdings of the special mortgage agencies the first phase of the mortgage movement comes to a close. In the movement here considered the development of volume continued for a decade following the close of the World War, the peak of farm-mortgage debt for the country apparently having been reached eight years after the price peak of 1920.

SOURCES OF FARM-MORTGAGE FUNDS

RELATIVE IMPORTANCE OF LENDING AGENCIES

The distribution of farm mortgages held by lending agencies undergoes continual change in proportions varying largely with the stage of activity in contracting new mortgages. During periods of active land transfers such as 1918 to 1920 the proportion of mortgages held by individuals and commercial banks rises as former owners take back mortgages on payment and banks use resources in facilitating transfers. During recent years the general tendency has been a shifting of loans from former owners, other individuals, and commercial banks, to insurance companies, Federal land banks, joint-stock land banks, and other agencies that specialize in long-term investments. This transfer was especially marked during the early post-

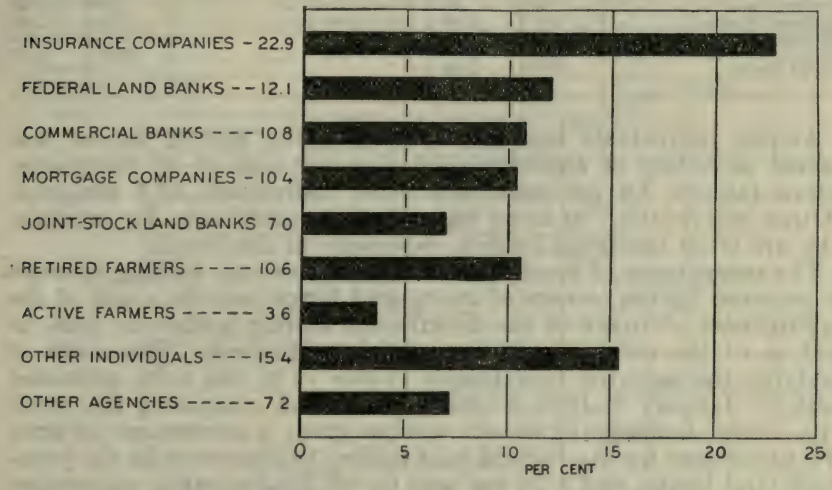

FIGURE 3.—FARM MORTGAGES HELD, BY CLASS OF LENDERS, JAN. 1, 1928

Since 1922, life-insurance companies have been the principal source of farm-mortgage loans in the United States. In 1928 they held nearly 23 per cent of the total of such loans. The Federal land banks were second in importance among institutions with 12.1 per cent, commercial banks third with 10.8 per cent, while mortgage companies had 10.4 per cent and joint-stock land banks 7 per cent. A total of 29.6 per cent of farm mortgages was held by individuals.

war years, when extensive refunding of short-term loans was adding materially to the volume of farm mortgages. (Fig. 3.)

The distribution of loans among nine principal classes of lending agencies as reported for January 1, 1928, indicates that life-insurance companies led all other sources of farm-mortgage funds with 22.9 per cent of all outstanding farm mortgages, or approximately $2,164,000,000. (Table 7.) The 12 Federal land banks were next in importance among the centralized major institutions, with 12.1 per cent or $1,146,000,000, and the joint-stock land banks, the other mortgage branch of the Federal system, had 7 per cent, or $667,000,000. Holdings of commercial banks were nearly equal to those of the Federal land banks, with an indicated percentage of 10.8 of the total, or $1,020,000,000. This represents a material decline since December 31, 1920, when the mortgage holdings of banks were estimated at $1,447,500,000 (*28*). Mortgage companies have a relative importance similar to commercial banks with 10.4 per cent of the total.

It is possible that the percentages indicated for mortgage companies and banks are too high since a large part of the mortgages negotiated by these agencies are sold later, although the companies or banks may continue to act as agents in making collections of interest and principal. In some instances, therefore, farmers might not be certain as to the holder of the mortgage at a given time.

TABLE 7.—*Farm mortgages held by nine principal classes of lending agencies in the United States, January 1, 1928*

Lending agencies	Percentage held	Amount held	Lending agencies	Percentage held	Amount held
	Per cent	*Million dollars*		*Per cent*	*Million dollars*
Federal land banks	12.1	1,146	Active farmers	3.6	339
Joint-stock land banks	7.0	667	Other individuals	15.4	1,453
Commercial banks	10.8	1,020	Other agencies	7.2	685
Mortgage companies	10.4	988			
Insurance companies	22.9	2,164	Total	100.0	9,468
Retired farmers	10.6	1,006			

Among individuals holding farm loans the retired farmer was named as holder of approximately 10.6 per cent of all mortgages, active farmers 3.6 per cent, and other individuals 15.4 per cent. "Other individuals," in many cases includes merchants, for example, who are often mortgage holders, especially in the South.

The percentages of mortgages held by the various lending agencies as reported by the owners of mortgaged farms provide a test of the approximate accuracy of the distribution among holders in 1928, as well as of the estimates of the total indebtedness. The result of applying the reported percentages (Table 7) to the total estimated debt for January 1, 1928, $9,468,526,000, and comparing the result with actual holdings of known sources gives a percentage of error of 0.52 per cent for the Federal land banks; 1.42 per cent for the joint-stock land banks, and 3.28 per cent for all life-insurance companies, or a total error of 1.69 per cent for the three agencies holding 42 per cent of the farm mortgages of the country. (Table 2.) The larger difference shown for insurance companies may be due to a difference in the proportion of assets in the form of mortgages held by nonreporting companies, as compared with the 52 companies having 92 per cent of the assets of all legal-reserve companies, on which the estimated total has been computed. (Table 45.)

TREND OF PRINCIPAL LENDERS' HOLDINGS

During the decade 1920 to 1930 important changes occurred in the relative importance of the principal lenders on farm mortgages.

The decreasing percentage of commercial bank holdings from 18.4 to 10.8 during the period 1920 to 1928, and the increase during that time, from 16.7 per cent to 42 per cent, of long-term loans held by three specializing agencies is indicative of the general movement. (Table 8.) Life-insurance companies assumed the leading position soon after 1921 (*5, 1923*). Insurance loans followed a steadily rising curve after 1920, with successively smaller annual increases after 1924 until a peak was reached at the close of 1927 and a downward turn appeared in 1928 and 1929. The relative position of loans by insurance com-

panies had risen from 12.4 per cent of the total in 1920 to 22.9 per cent of the total in 1928. (Fig. 4.)

TABLE 8.—*Percentages of farm-mortgage debt in the United States held by principal lending agencies, January 1, 1920, 1925, and 1928*

Lending agency	1920	1925	1928
	Per cent	*Per cent*	*Per cent*
Life-insurance companies	12.4	20.7	22.9
Federal land banks	3.6	9.9	12.1
Joint-stock land banks	.7	4.8	7.0
Commercial banks	[1] 18.4	----------	10.8
National banks only	2.1	2.7	3.4

[1] Dec. 31.

Loans of the joint-stock land banks also rose steadily from 1922 to a peak at the beginning of 1928; the rate of increase slackened during

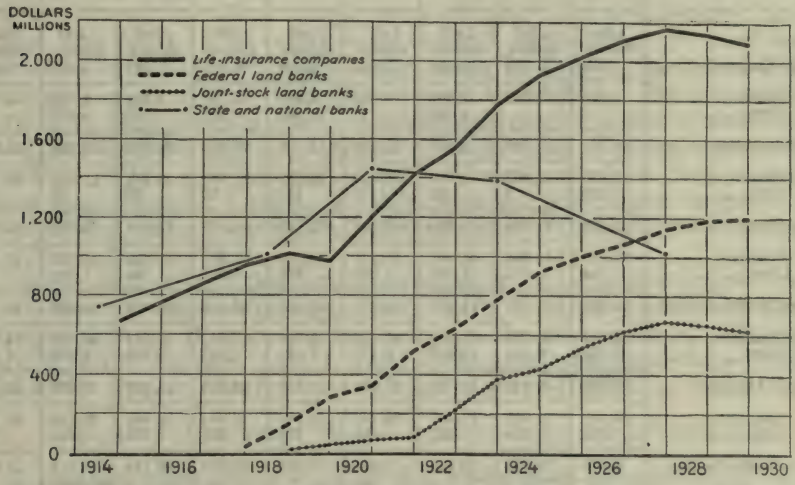

FIGURE 4.—TREND OF FARM-MORTGAGE HOLDINGS OF PRINCIPAL LENDING AGENCIES, 1914–1929

The volume of farm-mortgage loans held by all lenders moved steadily upward until the depression following 1920. Extensive refunding of mortgages held by commercial banks began a decline in their holdings but contributed to the continued rise of loans held by life-insurance companies and the Federal and joint-stock land banks. The loans of insurance companies and the joint-stock land banks reached a peak in 1928; the loans of the Federal land banks continued slightly upward until the middle of 1929.

1927 and turned downward during 1928 and 1929. The decline in joint-stock loans after the close of 1927 may have been in part a reflection of the difficulties confronting certain of those banks, involving extensive foreclosures by many and the receivership of three institutions. The reversal of the upward trend, however, coincides with the similar change in insurance loans.

State and national banks began a reduction of their land-secured loans as a part of the readjustment process following 1920. Because of extensive funding of customers' short-term loans into mortgages, and the subsequent but delayed transfer of loans to other agencies, the peak of mortgages held by banks in many sections of the country, and probably for the country as a whole, was not reached until sometime after the first of 1921, the date of which the highest total of

available data appears. By the first of 1924 the total volume of mortgages held by the banks had become less, and thereafter the decline became more pronounced. (Table 13.)

Farm-mortgage holdings of the various classes of commercial banks show the same declining tendency, with the exception of national banks. In this class, country national-bank holdings, which until 1927 were nine-tenths of the mortgages in all national banks, increased abruptly from 1921 to 1923 but have since remained nearly constant at the maximum level reached in 1925 (*23*). (Table 9.) The fact that the Federal and joint-stock land banks were largely out of the market in 1920–21 brought a heavier demand upon the commercial banks during that period.

TABLE 9.—*Real estate loans of national banks, secured by farm lands*

Geographic division and class of bank	1921	1922	1923	1924	1925	1926	1927	1928	1929
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
New England	1,678	2,065	12,130	3,083	4,326	3,863	5,281	5,877	5,399
Country	1,676	2,065	2,465	3,083	3,884	3,743	4,622	4,958	5,397
City	2		9,665		442	120	659	919	2
Middle Atlantic	6,111	7,599	9,208	11,953	14,568	17,563	20,207	21,266	24,560
Country	5,655	7,592	9,083	11,835	14,252	17,525	20,168	21,169	24,522
City	456	7	125	118	316	38	39	97	38
East North Central	36,974	42,118	45,550	48,221	51,070	54,382	52,454	56,295	56,289
Country	36,430	41,304	44,441	47,201	50,106	53,381	51,660	55,095	55,527
City	544	814	1,109	1,020	964	1,001	794	1,200	762
West North Central	46,635	63,179	74,472	74,028	76,433	69,945	61,479	61,235	48,717
Country	39,911	56,727	63,999	65,857	66,648	61,952	54,813	54,826	44,225
City	6,724	6,452	10,473	8,171	9,785	7,993	6,666	6,409	4,492
South Atlantic	13,830	16,819	19,719	20,631	23,519	23,091	23,029	25,260	22,145
Country	13,247	16,265	19,167	20,136	23,099	22,489	22,348	24,245	21,470
City	583	554	552	495	420	602	681	1,015	675
East South Central	8,435	10,856	10,226	12,588	14,201	15,099	16,741	17,813	17,973
Country	8,078	9,904	9,836	12,277	13,591	14,769	15,973	17,290	16,566
City	357	952	390	311	610	330	768	523	1,407
West South Central	15,651	26,079	30,847	30,282	31,177	29,014	30,155	29,000	24,228
Country	13,673	22,513	25,391	25,532	26,529	25,522	25,776	25,271	20,897
City	1,978	3,566	5,456	4,750	4,648	3,492	4,379	3,729	3,331
Mountain	17,040	22,304	23,005	21,266	18,598	16,379	15,539	12,949	11,236
Country	15,725	20,519	20,288	18,266	15,719	13,772	13,472	11,244	9,677
City	1,315	1,785	2,717	3,000	2,879	2,607	2,067	1,705	1,559
Pacific	15,298	18,068	21,459	23,100	21,980	22,734	80,068	95,430	88,717
Country	13,690	15,104	15,571	16,910	18,292	18,743	18,018	16,996	15,415
City	1,608	2,964	5,888	6,190	3,688	3,991	62,050	78,434	73,302
United States	161,652	209,087	246,616	245,152	255,872	252,070	304,953	325,125	299,264
Country	148,085	191,993	210,241	221,097	232,120	231,896	226,850	231,094	213,696
City	13,567	17,094	36,375	24,055	23,752	20,174	78,103	94,031	85,568

Compiled from reports of the Comptroller of the Currency. (*23*.)

Farm mortgages reported for city national banks rose sharply during 1927–28. Principally because a large group of banks in the Pacific area was transferred from a State to a national basis, the total holdings of national banks rose from 2.7 per cent of the total mortgage debt in 1925 to 3.4 per cent in 1928.

All banks having membership in the Federal reserve system reduced their farm-mortgage holdings steadily from $489,000,000 in 1926, when first reported, to $387,000,000 in 1930 (*26*), most of the reduction occurring among State banks. Bank failures probably have been secondary to a policy of reducing long-term real estate loans as a cause of this decline. The amendments to the national bank act liberalizing the privileges of national banks in loaning on real estate have induced many new loans of that class and have aided in sustaining the volume of farm loans by national banks as compared with the marked decline for others.

Only the Federal land banks showed a continuous rise in the volume of farm mortgages held after 1928. An extensive network of over 4,600 national farm-loan associations offering favorable interest rates and a long term on the amortization basis, enabled the Federal land banks to expand their outstanding loans in every year until 1929. During that year their loans also began to decline. Because of the long-term amortization plan of land-bank credit, loans of this class have not become due on account of expiration of term, hence the question of renewal has not arisen. Foreclosure has been a more important factor. Partly on this account the total number of outstanding loans of the joint stock land banks was smaller in 1929 than in 1928. (Table 12.)

Taken as a whole this pronounced shift of farm mortgages from local agencies dependent upon local funds to large centralized institutions drawing their resources from a wide area must be adjudged as a definite improvement toward stabilizing the conditions under which the farmer obtains approximately three-fourths of his credit.[5]

VARIATIONS IN LENDERS' HOLDINGS AMONG GEOGRAPHIC DIVISIONS

A marked variation occurs in the proportion of total loans held by each of the lending agencies among various sections. Although insurance companies, the largest lenders, in 1928 had nearly 23 per cent of the total loans for the country as a whole, these loans were concentrated in the four geographic divisions centering on the Mississippi Valley, where they hold from 19 per cent of the total loans in the East North Central to 32 per cent of the total in the West North Central, the most heavily indebted division. This indicates the large part played by insurance loans in the area of greatest farm-credit demand. (Table 10.)

[5] An illustration of the process of shifting mortgages among various holders is shown for a local area by Table 41. (*13.*)

TABLE 10.—*Percentage distribution of holdings of principal lending agencies, by geographic divisions, January 1, 1928*

Geographic division	Total farm mortgage debt 1928	Holdings of principal lending agencies								
		Federal land banks	Joint-stock land banks	Commercial banks	Mortgage companies	Insurance companies	Retired farmers	Active farmers	Other individual	Other agencies
	1,000 dollars	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
New England	122,494	16.6	-------	37.7	-------	(1)	7.6	4.2	24.8	9.
Middle Atlantic	376,614	11.7	6.0	10.5	0.5	0.1	19.3	9.8	34.8	7.
East North Central	1,950,126	8.2	7.7	14.0	5.8	19.4	14.1	5.2	17.2	8.
West North Central	4,056,187	7.0	5.4	6.2	15.1	32.3	11.8	3.1	13.3	5.
South Atlantic	491,896	21.7	16.4	10.7	1.5	12.5	4.4	2.0	23.8	7.
East South Central	381,497	34.5	7.3	11.1	2.8	28.0	3.9	2.6	7.4	2.
West South Central	901,252	23.7	11.3	4.1	14.9	25.0	4.1	1.3	7.6	8.
Mountain	496,551	21.8	4.7	16.7	14.9	5.6	7.0	3.0	19.3	7.
Pacific	691,909	11.4	6.2	28.1	5.3	7.7	9.1	3.1	15.2	13.
United States	9,468,526	12.1	7.0	10.8	10.4	22.9	10.6	3.6	15.4	7.

[1] Less than 0.05 per cent.

The farm-mortgage loans of commercial banks are more evenly distributed than are those of other institutions that lend on farm real estate security. Reports from farmers indicate that farm mortgages held by commercial banks averaged 10.8 per cent of all such loans for the country as a whole in 1928. This average had two outstanding variations—38 per cent of the total of New England mortgages, and over 28 per cent of the farm mortgages in the Pacific States.[6] Loans from this source have their smallest proportion of total debt in the West South Central and in the West North Central divisions. Both of these important centers of demand for agricultural credit have found an increasing accommodation among the more specialized sources of mortgage credit.

Mortgage companies, with 10.4 per cent of the total loans of the country, show proportions in excess of this figure in the West North Central, the West South Central, and the Mountain divisions where the proportion is approximately 15 per cent of the total mortgage indebtedness of each of those divisions.

Retired farmers are reported as holders of mortgages to the extent of 10.6 per cent of the total. In the Middle Atlantic, East North Central, and West North Central divisions, however, the proportion of holdings reported for this source are respectively 19, 14, and 12 per cent, thus indicating the concentration of credit in those areas in which land values have reached highest levels and in which transfers have been more numerous.

Mortgage loans held by active farmers show concentrations similar to those held by retired farmers but have a much lower average—3.6 per cent of the total in the country. The rather uniform ratio of 2 or 3 to 1, which the mortgage holdings of retired farmers bear to the loans held by active farmers, is observable in all areas.

Loans from other individuals, averaging 15.4 per cent for the country as a whole, show the larger percentages of 34.8 per cent in the

[6] The distribution of percentages, covering mortgage debt held by commercial banks, mortgage companies and individuals, is based upon reports from farmers in selected counties and is therefore subject to more variation than is the distribution for insurance companies and the Federal and joint-stock land banks based upon more complete data. The percentages for the former group of sources are to be considered as preliminary indicators of relative importance of the respective lending agencies.

Middle Atlantic, 24.8 in New England, and 23.8 in the South Atlantic divisions. These loans reflect three principal sources—loans from professional men living in towns adjacent to farming territory, loans from merchants or other dealers who have taken mortgages often as a means of funding short-time credit extended at an earlier date, and mortgages held by former owners.

The distribution of loans made by the Federal and joint-stock land banks indicates that these agencies have responded to the demand for credit in areas hitherto not emphasized by the leading mortgage agencies. The concentration of loans from commercial banks in the Northeast and in the Pacific States reflects the abundance of funds which banks in those territories have had available for long-term loans. (Tables 11 and 12.)

Thus in 1928 more than one-third of New England's farm-mortgage credit was supplied by individuals, and an equal amount by banks. The Middle Atlantic States had two-thirds of its mortgage credit from individuals, and the East North Central States had more than one-third from this source. All three northeastern divisions had from 16 to 17 per cent of their loans from the Federal and joint-stock land banks. The West North Central division drew over 32 per cent of its long-term credit from insurance companies, 15 per cent from mortgage companies, more than 25 per cent from individuals, but only 12 per cent from the Federal and joint-stock land banks. The South Atlantic division, however, received 38 per cent of its loans from the land banks; the East South Central division had the largest proportion with 42 per cent of its total from this source, and 28 per cent from insurance companies; and the West South Central division had 35 per cent from the land banks, and 25 per cent from insurance companies. In the Pacific division, as in New England, the greater part of the loans were made by commercial banks and individuals.

TABLE 11.—*Number and amount of Federal land-bank loans, outstanding December 31, 1926, 1927, 1928, and 1929, by States and geographic divisions*

State and geographic division	Loans				Amount			
	1926	1927	1928	1929	1926	1927	1928	1929
	Number [1]	*Number* [1]	*Number* [2]	*Number* [2]	*1,000 dollars* [1]	*1,000 dollars* [1]	*1,000 dollars* [2]	*1,000 dollars* [2]
Maine	2,569	2,732	2,771	2,798	6,579	6,746	6,664	6,593
New Hampshire	497	526	527	504	999	1,069	1,083	1,014
Vermont	1,195	1,386	1,397	1,368	3,366	3,938	3,877	3,707
Massachusetts	1,371	1,457	1,482	1,527	3,639	3,983	4,040	4,153
Rhode Island	114	129	152	169	362	423	461	518
Connecticut	1,262	1,319	1,360	1,421	3,949	4,134	4,216	4,331
New England	7,008	7,549	7,689	7,787	18,894	20,293	20,341	20,316
New York	6,459	7,442	7,904	8,099	20,749	24,061	24,851	25,048
New Jersey	1,106	1,302	1,358	1,427	4,146	4,856	4,987	5,208
Pennsylvania	5,650	6,113	6,715	6,967	14,300	15,187	16,399	16,696
Middle Atlantic	13,215	14,857	15,977	16,493	39,195	44,104	46,237	46,952
Ohio	5,765	6,378	6,936	7,202	21,741	23,883	25,832	26,247
Indiana	11,501	12,828	13,977	14,471	39,572	43,471	46,811	47,554
Illinois	5,901	6,993	8,179	8,805	29,052	38,051	47,624	52,497
Michigan	9,008	9,758	10,087	10,199	23,016	24,988	25,389	25,311
Wisconsin	7,223	7,411	7,351	7,287	28,227	28,819	28,268	27,584
East North Central	39,398	43,368	46,530	47,964	141,608	159,212	173,924	179,193

[1] Data from the Federal Farm Loan Board.
[2] Data from annual reports of the Federal Farm Loan Board (*25*).

TABLE 11.—*Number and amount of Federal land-bank loans, outstanding December 31, 1926, 1927, 1928, and 1929, by States and geographic divisions*—Continued

State and Geographic Division	Loans				Amount			
	1926	1927	1928	1929	1926	1927	1928	1929
	Number	*Number*	*Number*	*Number*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
Minnesota	8,405	8,581	8,563	8,526	36,727	37,903	37,622	36,953
Iowa	7,730	8,807	9,636	10,098	59,899	69,732	77,345	80,433
Missouri	8,710	9,222	9,573	9,619	26,961	29,102	30,759	30,954
North Dakota	9,672	9,667	9,281	9,137	36,561	36,328	34,289	33,064
South Dakota	5,595	6,131	6,337	6,452	27,292	29,870	30,844	30,795
Nebraska	8,070	8,709	9,085	9,092	41,965	45,834	48,292	47,728
Kansas	8,637	8,980	8,911	8,675	34,222	34,935	34,462	32,920
West North Central	56,819	60,097	61,386	61,599	263,627	283,704	293,613	292,847
Delaware	118	128	137	138	376	385	424	416
Maryland	996	1,013	1,032	1,068	3,727	3,745	3,947	4,037
Virginia	11,352	11,664	11,889	11,895	28,207	28,472	28,642	28,283
West Virginia	3,729	4,100	4,488	4,547	6,971	7,624	8,102	8,112
North Carolina	10,078	10,246	10,231	10,205	18,734	18,711	18,321	17,866
South Carolina	6,198	6,422	6,223	5,964	16,678	16,817	15,873	14,719
Georgia	10,397	11,148	11,265	11,151	23,458	24,405	23,971	23,143
Florida	3,291	3,626	3,787	3,764	5,859	6,655	6,793	6,611
South Atlantic	46,159	48,347	49,052	48,732	104,010	106,814	106,073	103,187
Kentucky	8,289	8,882	9,219	9,245	24,164	25,241	25,561	25,189
Tennessee	9,992	10,729	11,219	11,393	23,281	24,213	24,864	24,703
Alabama	19,904	22,197	22,649	22,957	34,321	38,037	38,321	38,314
Mississippi	22,234	23,296	23,367	23,665	42,211	44,056	43,089	42,500
East South Central	60,419	65,104	66,454	67,260	123,977	131,547	131,835	130,706
Arkansas	13,890	14,471	14,811	14,732	22,731	23,836	24,214	23,829
Louisiana	12,233	12,803	12,803	12,812	28,719	29,656	29,221	28,547
Oklahoma	7,134	7,371	7,683	7,856	18,675	19,931	20,660	20,885
Texas	46,780	52,014	54,813	56,387	126,630	139,869	146,805	150,782
West South Central	80,037	86,659	90,110	91,787	196,755	213,292	220,900	224,043
Montana	6,986	7,052	7,149	7,055	20,312	20,708	21,231	21,038
Idaho	6,680	6,772	6,860	6,897	22,491	22,682	22,768	22,683
Wyoming	2,344	2,355	2,336	2,298	7,181	7,168	7,022	6,812
Colorado	8,301	8,643	8,771	8,863	23,871	24,986	25,206	25,209
New Mexico	4,848	5,003	4,985	4,961	9,903	10,192	10,102	9,924
Arizona	1,375	1,456	1,483	1,487	5,520	5,742	5,720	5,701
Utah	4,811	5,060	5,139	5,222	14,295	14,697	14,670	14,706
Nevada	255	349	386	404	1,278	2,333	2,739	2,872
Mountain	35,600	36,690	37,109	37,187	104,851	108,508	109,458	108,945
Washington	11,564	11,871	12,151	12,116	30,590	30,984	31,565	31,317
Oregon	6,265	6,286	6,278	6,169	20,069	20,016	19,737	19,208
California	6,811	7,458	7,789	7,881	25,066	27,959	29,130	29,051
Pacific	24,640	25,615	26,218	26,166	75,725	78,959	80,432	79,576
United States	363,295	388,286	400,525	404,975	1,068,642	1,146,433[3]	1,182,813	1,185,765

[3] This amount exceeds the total reported in the twelfth annual report of the Farm Loan Board (*25, Rpt. 12, p. 20*) by $1,449,252.48 for which segregation by States is not available. Of this amount $479,752.48 consisted of purchase money, first and second mortgages for the Federal Land Bank of Springfield, and $969,500 of loans in suspense for the Federal Land Bank of St. Paul.

TABLE 12.—*Number and amount of joint-stock land bank loans, outstanding December 31, 1926, 1927, 1928, and 1929, by geographic divisions and States*

State and geographic division	Loans				Amount			
	1926[1]	1927[1]	1928[2]	1929[2]	1926[1]	1927[1]	1928[2]	1929[2]
	Number	*Number*	*Number*	*Number*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
New York	1,780	2,400	2,662	2,734	9,708	[3] 11,380	11,962	11,944
New Jersey	406	455	461	448	2,091	2,291	2,267	2,192
Pennsylvania	1,981	2,371	2,601	2,605	8,092	9,017	9,484	9,194
Middle Atlantic	4,167	5,226	5,724	5,787	19,891	22,688	23,713	23,330
Ohio	5,751	6,263	6,584	6,559	27,461	28,266	28,553	27,590
Indiana	6,028	7,044	7,428	7,602	34,854	36,234	36,991	36,522
Illinois	8,672	8,703	8,830	8,844	68,550	73,153	71,763	70,996
Michigan	1,593	2,035	2,151	2,159	7,446	9,069	9,228	8,990
Wisconsin	969	925	832	767	4,676	4,340	3,758	3,307
East North Central	23,013	24,970	25,825	25,931	142,987	151,062	150,293	147,405
Minnesota	4,204	3,993	3,665	3,253	34,667	32,128	28,443	23,911
Iowa	8,187	8,357	8,258	8,044	90,772	90,061	91,258	86,912
Missouri	3,778	3,789	3,388	3,187	27,324	24,965	21,494	19,473
North Dakota	772	746	734	722	4,298	4,103	3,959	3,810
South Dakota	1,673	1,530	1,407	1,289	13,370	11,939	10,570	9,533
Nebraska	2,976	3,270	3,316	3,277	29,209	30,854	26,444	25,824
Kansas	3,834	3,939	3,438	3,150	23,696	22,681	19,672	17,368
West North Central	25,424	25,624	24,206	22,922	223,336	216,731	201,840	186,831
Maryland	534	689	752	758	3,032	4,199	4,400	4,247
Virginia	2,022	2,310	2,424	2,376	9,084	10,073	10,279	9,759
West Virginia	1,947	1,999	1,938	1,872	5,345	5,339	5,044	4,678
North Carolina	9,895	11,666	12,595	12,615	33,648	38,016	39,512	38,264
South Carolina	2,434	2,792	2,814	2,641	13,320	14,211	13,964	12,402
Georgia	1,364	1,648	1,781	1,775	7,166	8,573	9,157	8,721
South Atlantic	18,196	21,104	22,304	22,037	71,595	80,411	82,356	78,071
Kentucky	2,084	2,148	2,142	2,115	11,165	11,701	11,342	10,896
Tennessee	732	764	793	784	2,993	3,037	3,046	2,978
Alabama	782	947	1,015	1,002	5,244	5,928	6,124	5,876
Mississippi	356	490	500	501	6,889	7,199	7,239	7,083
East South Central	3,954	4,349	4,450	4,402	26,291	27,865	27,751	26,833
Arkansas	1,367	1,622	1,646	1,644	12,217	13,505	13,409	13,101
Louisiana	63	65	64	61	1,133	1,176	1,160	1,133
Oklahoma	937	1,133	1,054	997	4,840	5,348	4,906	4,558
Texas	9,983	11,834	12,255	11,983	71,747	82,235	83,387	80,170
West South Central	12,350	14,654	15,019	14,685	89,937	102,264	102,862	98,962
Montana	319	287	275	262	1,840	1,687	1,604	1,526
Idaho	746	879	953	1,020	3,329	3,787	3,933	4,021
Wyoming	654	677	660	640	4,589	4,599	4,315	4,073
Colorado	1,124	1,375	1,425	1,392	7,494	9,027	9,247	8,819
Arizona	365	431	493	494	2,465	2,911	3,261	3,132
Utah	163	165	169	166	713	685	671	635
Nevada	29	30	32	30	524	623	645	634
Mountain	3,400	3,844	4,007	4,004	20,954	23,319	23,676	22,840
Washington	200	210	213	206	2,015	2,044	1,994	1,854
Oregon	1,017	1,118	1,135	1,151	11,137	11,924	11,893	11,668
California	2,052	2,424	2,598	2,606	24,367	29,006	30,138	29,186
Pacific	3,269	3,752	3,946	3,963	[4] 37,583	42,974	44,025	42,708
United States	93,780	103,523	105,481	103,731	[4] 632,574	[5] 667,314	656,516	626,980

[1] Data from Federal Farm Loan Board.
[2] 1928 and 1929 from annual reports of Federal Farm Loan Board.
[3] This amount includes $76,298.58, part of which was in New Jersey. A segregation by States is not available. The number of loans represented by this amount also is not available.
[4] Includes 7 loans in the amount of $64,567.57 outstanding in Oregon and Washington for which a segregation between the two States is not available. These totals differ from those shown by the Federal Farm Loan Board (*25, Rpt. 12, p. 31*) by $98,310.28 for which a segregation by States is not available.
[5] This differs from the total reported by the Federal Farm Loan Board (*25 Rpt. 12, p. 31.*) as follows: It includes $2,631,141.78 of payments on principal for the Kansas City Joint-Stock Land Bank which has been deducted in compiling the figures of that bank for the annual report. A segregation by States of these figures is not available.

SECTIONAL DIFFERENCES IN LOAN HOLDINGS SINCE 1914

The course of loans by insurance companies and land banks from pre-war years to 1924 followed a generally upward trend in most of the geographic divisions similar to the movement for the country as a whole. Significant sectional differences emphasize two features—the continued demand for capital in the west central and Pacific divisions up to recent years, and the centering of insurance-loan peaks for the three eastern divisions in 1922 and 1923 and for the Mountain division in 1924. (Table 13.)

TABLE 13.—*Farm mortgage loans held by principal lending agencies in geographic divisions, December 31, 1914 and 1916–1929*

Geographic division	Lending agency	1914	1916	1917	1918[1]	1919
		1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
New England	Insurance companies	108	79	35	34	34
	Federal land banks					
	Joint-stock land banks					
	State and national banks	84,900			96,300	
	National banks (country)					
Middle Atlantic	Insurance companies	370	489	390	317	137
	Federal land banks					
	Joint-stock land banks					
	State and national banks	30,900			58,787	
	National banks (country)					
East North Central	Insurance companies	120,475	141,250	147,689	152,283	145,322
	Federal land banks					
	Joint-stock land banks					
	State and national banks	220,000			252,707	
	National banks (country)					
West North Central	Insurance companies	412,356	526,118	603,243	631,252	618,783
	Federal land banks					
	Joint-stock land banks					
	State and national banks	216,400			296,538	
	National banks (country)					
South Atlantic	Insurance companies	21,559	31,993	31,236	32,275	39,228
	Federal land banks					
	Joint-stock land banks					
	State and national banks	40,800			53,129	
	National banks (country)					
East South Central	Insurance companies	20,104	31,827	36,282	41,272	39,112
	Federal land banks					
	Joint-stock land banks					
	State and national banks	33,600			52,023	
	National banks (country)					
West South Central	Insurance companies	67,592	90,229	98,911	115,719	96,568
	Federal land banks					
	Joint-stock land banks					
	State and national banks	27,900			34,503	
	National banks (country)					
Mountain	Insurance companies	12,130	16,657	15,551	20,067	13,545
	Federal land banks					
	Joint-stock land banks					
	State and national banks	19,800			27,621	
	National banks (country)					
Pacific	Insurance companies	12,621	19,079	18,447	20,888	18,213
	Federal land banks					
	Joint-stock land banks					
	State and national banks	65,200			138,951	
	National banks (country)					
United States	Insurance companies	667,315	857,721	951,784	1,014,107	970,942
	Federal land banks					
	Joint-stock land banks					
	State and national banks	739,500			1,010,559	
	National banks (country)					

[1] Date of State and national bank data for 1918 as of June 30.

TABLE 13.—*Farm mortgage loans held by principal lending agencies in geographic divisions, December 31, 1914 and 1916–1929*—Continued

Geographic division	Lending agency	1920	1921	1922	1923	1924
		1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
New England	Insurance companies	30	32	66	57	56
	Federal land banks					
	Joint-stock land banks					
	State and national banks	93,686			111,918	
	National banks (country)		1,676	2,065	2,465	3,083
Middle Atlantic	Insurance companies	133	476	503	862	509
	Federal land banks					
	Joint-stock land banks					
	State and national banks	34,148			37,510	
	National banks (country)		5,655	7,592	9,083	11,835
East North Central	Insurance companies	168,894	198,085	222,041	269,042	309,986
	Federal land banks					
	Joint-stock land banks					
	State and national banks	335,095			315,131	
	National banks (country)		36,430	41,304	44,441	47,201
West North Central	Insurance companies	757,126	877,736	940,027	1,090,859	1,179,992
	Federal land banks					
	Joint-stock land banks					
	State and national banks	531,212			403,514	
	National banks (country)		39,911	56,727	63,999	65,857
South Atlantic	Insurance companies	51,005	67,467	70,907	72,335	71,102
	Federal land banks					
	Joint-stock land banks					
	State and national banks	94,048			79,856	
	National banks (country)		13,247	16,265	19,167	20,136
East South Central	Insurance companies	53,715	69,347	76,092	89,470	98,318
	Federal land banks					
	Joint-stock land banks					
	State and national banks	101,080			77,591	
	National banks (country)		8,078	9,904	9,836	12,277
West South Central	Insurance companies	131,121	168,274	185,481	200,147	206,145
	Federal land banks					
	Joint-stock land banks					
	State and national banks	73,251			82,306	
	National banks (country)		13,673	22,513	25,391	25,532
Mountain	Insurance companies	19,010	21,565	25,003	27,462	28,320
	Federal land banks					
	Joint-stock land banks					
	State and national banks	55,936			52,408	
	National banks (country)		15,725	20,519	20,288	18,266
Pacific	Insurance companies	19,940	23,678	29,883	34,771	40,456
	Federal land banks					
	Joint-stock land banks					
	State and national banks	114,321			227,872	
	National banks (country)		13,690	15,104	15,571	16,910
United States	Insurance companies	1,200,974	1,426,660	1,550,003	1,785,005	1,934,884
	Federal land banks					
	Joint-stock land banks					
	State and national banks	1,447,483			1,388,106	
	National banks (country)		148,085	191,993	210,241	221,097

Geographic division	Lending agency	1925	1926	1927 [2]	1928	1929
		1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
New England	Insurance companies	45	46	43	41	
	Federal land banks		18,894	20,293	20,341	20,316
	Joint-stock land banks					
	State and national banks			46,209		
	National banks (country)	3,884	3,743	4,622	4,951	
Middle Atlantic	Insurance companies	467	412	359	291	
	Federal land banks		39,195	44,104	46,237	46,952
	Joint-stock land banks		19,891	22,688	23,713	23,330
	State and national banks			39,331		
	National banks (country)	14,252	17,525	20,168	21,169	
East North Central	Insurance companies	339,100	366,981	378,833	378,035	
	Federal land banks		141,608	159,212	173,924	179,193
	Joint-stock land banks		142,987	151,062	150,293	147,405
	State and national banks			272,794		
	National banks (country)	50,106	53,381	51,660	55,095	
West North Central	Insurance companies	1,231,346	1,281,056	1,310,571	1,284,226	
	Federal land banks		263,627	283,704	293,613	292,847
	Joint-stock land banks		223,336	216,731	201,840	186,831
	State and national banks			252,131		
	National banks (country)	66,648	61,952	54,813	54,826	

[2] Holdings of banks, including all commercial banks. Estimates are based upon sample reports of borrowers and therefore merit less confidence than figures on bank loans for other years, when data were based upon reports from the source.

TABLE 13.—*Farm mortgage loans held by principal lending agencies in geographic divisions, December 31, 1914 and 1916–1929*—Continued

Geographic division	Lending agency	1925	1926	1927	1928	1929
		1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
South Atlantic	Insurance companies	67,026	65,739	61,667	58,841	
	Federal land banks		104,010	106,814	106,073	103,187
	Joint-stock land banks		71,595	80,411	82,356	78,071
	State and national banks			52,700		
	National banks (country)	23,099	22,489	22,348	24,245	
East South Central	Insurance companies	102,600	106,931	106,873	103,809	
	Federal land banks		123,977	131,547	131,835	130,706
	Joint-stock land banks		26,291	27,865	27,751	26,833
	State and national banks			42,286		
	National banks (country)	13,591	14,769	15,973	17,290	
West South Central	Insurance companies	210,407	219,183	225,134	222,838	
	Federal land banks		196,755	213,292	220,900	224,043
	Joint-stock land banks		89,937	102,264	102,862	98,962
	State and national banks			37,152		
	National banks (country)	26,529	25,522	25,776	25,271	
Mountain	Insurance companies	26,956	26,430	27,614	27,861	
	Federal land banks		104,851	108,508	109,458	108,945
	Joint-stock land banks		20,954	23,319	23,676	22,840
	State and national banks			[3] 82,876		
	National banks (country)	15,719	13,772	13,472	11,244	
Pacific	Insurance companies	44,265	48,425	53,102	54,516	
	Federal land banks		75,725	78,959	80,432	79,576
	Joint-stock land banks		37,583	42,974	44,025	42,708
	State and national banks			194,840		
	National banks (country)	18,292	18,743	18,018	16,996	
United States	Insurance companies	2,022,222	2,115,203	2,164,206	2,130,458	2,100,429
	Federal land banks		1,068,642	1,146,433	1,182,813	1,185,765
	Joint-stock land banks		632,574	667,314	656,516	626,980
	State and national banks			1,020,319		
	National banks (country)	232,120	231,896	226,850	231,094	

[3] Preliminary. This figure is probably too high.

Mortgage loans by State and national banks were of larger volume at the close of 1920 than at the end of 1923 in five divisions and for the country as a whole, but in the North Atlantic, West South Central, and Pacific divisions holdings of the banks were greater in 1923 than in 1920. The increase of loans in these divisions reflected strong bank resources, though in the West South Central and Pacific divisions expanding agriculture also brought about increased demand for farm credit.

The relative increase in farm-mortgage loans by insurance companies during the 15 years 1914 to 1928 was greatest in the East South Central States where their holdings grew to five times the amount outstanding in 1914. During this period insurance-company loans in the Pacific division mounted to more than four times the volume outstanding in 1914, trebled in the two North Central divisions, South Atlantic, and West South Central divisions, and more than doubled in the Mountain States. The Middle Atlantic States had about the same amount of insurance loans in 1927 as in 1914 but had less at the close of 1928, and the New England States were using only two-fifths as much capital from this source in 1928 as in 1914.

The West Central States, both northern and southern, drew their greatest amount of mortgage funds from insurance companies in 1927. Loans in the West North Central division first amounted to $1,000,000,000 in 1923, reaching $1,310,000,000 four years later for a total of 59 per cent of all farm mortgages held by those agencies. The East North Central and the Pacific divisions received the most nearly continuous increase in loans from insurance companies during the 14

years following 1914, the first-named division having $378,000,000 and the Pacific $55,000,000 in 1928. (Table 14.)

TABLE 14.—*Estimated farm-mortgage loans of all life insurance companies in the United States by geographic divisions, December 31, 1914–1929*

Year	United States	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
1914	667,315	108	370	120,475	412,356	21,559	20,104	67,592	12,130	12,621
1916	857,721	79	489	141,250	526,118	31,993	31,827	90,229	16,657	19,079
1917	951,784	35	390	147,689	603,243	31,236	36,282	98,911	15,551	18,447
1918	1,014,107	34	317	152,283	631,252	32,275	41,272	115,719	20,067	20,888
1919	970,942	34	137	145,322	618,783	39,228	39,112	96,568	13,545	18,213
1920	1,200,974	30	133	168,894	757,126	51,005	53,715	131,121	19,010	19,940
1921	1,426,660	32	476	198,085	877,736	67,467	69,347	168,274	21,565	23,678
1922	1,550,003	66	503	222,041	940,027	70,907	76,092	185,481	25,003	29,883
1923	1,785,005	57	862	269,042	1,090,859	72,335	89,470	200,147	27,462	34,771
1924	1,934,884	56	509	309,986	1,179,992	71,102	98,318	206,145	28,320	40,456
1925	2,022,222	45	467	339,110	1,231,346	67,026	102,600	210,407	26,956	44,265
1926	2,115,203	46	412	366,981	1,281,056	65,739	106,931	219,183	26,430	48,425
1927	2,164,206	43	359	378,833	1,310,571	61,677	106,873	225,134	27,614	53,102
1928	2,130,458	41	291	378,035	1,284,226	58,841	103,809	222,838	27,861	54,516
1929	2,100,429	36	268	379,984	1,261,589	56,680	100,314	217,888	27,604	56,066
1930	2,054,466									

Loans of the Federal land banks declined only in the South Atlantic division in 1928, but showed reductions in all but the Middle Atlantic, East North Central and West South Central divisions in 1929. The loans of joint-stock land banks declined in the East North Central, East South Central, and West North Central divisions in 1928, and in all divisions in 1929. Summarized by States, the amount of the Federal land-bank loans declined in four States in 1927, in 15 States in 1928, and in 29 States in 1929. (Table 11.) In general, for all areas where insurance loans have reached a peak and then declined, the volume of loans held by the joint-stock land banks and Federal land banks have continued to increase for some time afterward. In a similar manner the Federal land-bank loans have continued to grow in volume after the joint-stock land bank loans have begun to decrease.

Aside from differences in lending policy as applied to given areas, two general causes explain these divergent tendencies—the degree of freedom in the use of funds for making new loans and difference in maturity dates of loans already made. The usual short term of insurance loans brings to maturity approximately 15 to 20 per cent of outstanding loans each year. At these due dates complete payment may be received or a renewal of the loan may be granted under the same or different terms.

In brief, the funds may be distributed anew in such proportions as the lenders may desire. Insurance companies have many outlets for their funds; farm mortgages formed only 12 per cent of their total admitted assets in 1928, hence these agencies are free to invest wherever opportunity is most attractive and to shift their proportions of investments materially within a few years. On the other hand, the joint stock and the Federal land banks loan only for long terms and can use funds only for farm loans or for purchase of bonds which usually gives lower returns than do mortgage loans. The large

number of local associations of farmers acting as feeders to the Federal land banks also tends to sustain the volume of loans from that source.

LOANS BY INSURANCE COMPANIES AS INDICATORS OF FARM-MORTGAGE TRENDS

Mortgage loans by life-insurance companies are one of the most sensitive indicators of the flow of capital to or from agricultural areas. A wide system of local representatives has extended loan operations into all sections in a volume much above that from any other source. Supplied by a continuous stream of funds from the receipt of premiums, the insurance companies have at all times a large amount of capital available for investment in any one of several outlets. A flexible system of rates permits ready adjustment to money-market

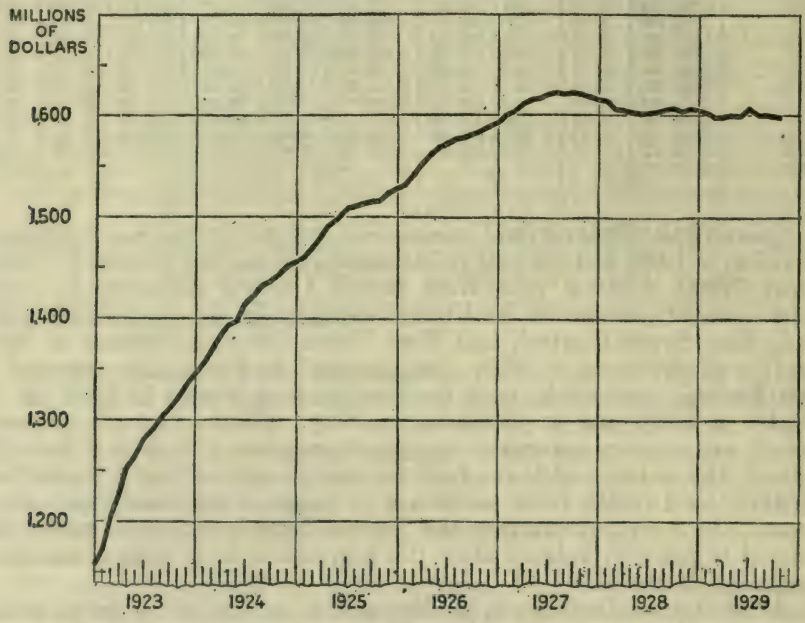

FIGURE 5.—FARM MORTGAGES OUTSTANDING: 40 LIFE-INSURANCE COMPANIES, BY MONTHS, 1923 TO 1929

Monthly reports on the volume of outstanding farm mortgages held by 40 life-insurance companies indicate a steady rise at a decreasing rate from 1923 to 1927. Since 1927 the volume of such holdings has shown a tendency to decline. (*21, p. 45.*)

changes or to new calculations of risk. Moreover, the average term of the loans is short, the great majority being made for five years, so that approximately from 15 to 20 per cent of the total falls due each year, to be reinvested. The policy of companies as to renewals and making new investments is soon reflected in the total outstanding investments in farm mortgages. (Figs. 5 and 6.)

DIFFERENCES IN SIZE OF LOANS

Noticeable differences appear in the average size of loans among the various geographic divisions, tenure groups, and sources of funds. Loans of all classes reported in 1928 averaged $5,200 for the country as a whole. Loans were largest in the West North Central States with an average of more than $8,000; the Pacific and East North

Central divisions came next with averages of $6,400 and $5,700, respectively; while loans were smallest in New England with an average of $1,680. (Table 15.) These averages, as well as those hereafter given for other classifications of tenure and source, are generally larger than the average for all farms because farmers responding to questionnaires usually have farms larger than average size and, hence, usually have larger mortgages. Although the comparisons made here with regard to size of loans are not in absolute

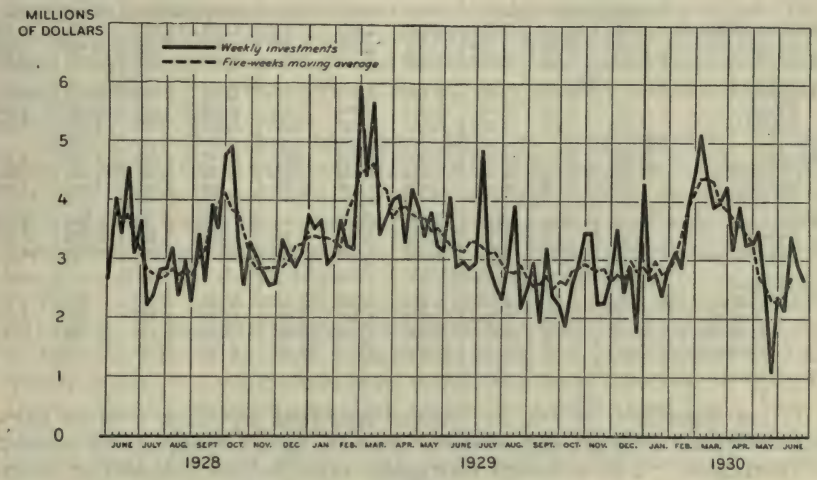

FIGURE 6.—WEEKLY INVESTMENTS IN FARM-MORTGAGE LOANS

Weekly investments in farm mortgage loans made by 25 leading life-insurance companies have shown lower peaks and lower averages than for corresponding earlier periods (*2*).

amounts, it is believed that they fairly represent relative differences in size among the various groups of lending agencies.

TABLE 15.—*Average size of outstanding mortgage loans held by principal lending agencies, by tenure and geographic divisions, January 1, 1928.*[1]

Geographic division and tenure	Average total holdings	Average holdings of principal lending agencies								
		Federal land banks	Joint stock land banks	Commercial banks	Mortgage companies	Insurance companies	Retired farmers	Active farmers	Other individuals	Other agencies
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*[1]
New England	1,680	2,825	----	1,623	----	850	1,612	1,318	1,520	1,710
Owners	1,643	2,800	----	1,599	----	850	1,605	1,218	1,501	1,557
Tenants	2,742	1,500	----	2,044	----	----	2,000	3,200	2,480	11,400
Middle Atlantic	2,414	3,072	3,555	1,936	3,167	3,640	2,332	1,950	2,366	2,678
Owners	2,191	2,735	2,757	1,786	2,250	1,800	2,184	1,911	2,261	1,829
Tenants	3,995	5,031	6,940	2,769	5,000	11,000	3,807	2,875	3,211	5,508
East North Central	5,722	5,300	8,054	4,736	6,348	9,806	5,108	4,149	5,052	3,171
Owners	4,462	3,837	6,773	4,102	4,246	7,363	5,110	3,076	4,418	2,487
Tenants	8,208	8,648	9,502	6,416	9,292	11,703	5,189	7,530	7,041	4,965
West North Central	8,079	5,764	10,422	5,480	8,208	12,566	7,974	5,890	6,931	4,607
Owners	6,254	5,160	10,076	4,050	5,982	9,589	7,092	3,773	5,813	3,687
Tenants	10,089	7,291	10,807	7,211	10,106	14,612	9,182	8,879	8,200	5,659
South Atlantic	3,895	2,970	5,030	4,381	3,589	5,450	3,365	2,100	3,879	5,078
Owners	3,149	2,920	4,015	4,629	1,680	4,017	2,158	1,628	2,895	3,746
Tenants	4,262	3,088	6,223	3,903	5,975	6,423	4,655	2,900	3,717	3,753

[1] Based on 8,942 loans reported by farm owners, 1928.

TABLE 15.—*Average size of outstanding mortgage loans held by principal lending agencies, by tenure and geographic divisions, January 1, 1928*—Continued

Geographic division and tenure	Average total holdings	Average holdings of principal lending agencies								
		Federal land banks	Joint stock land banks	Commercial banks	Mortgage companies	Insurance companies	Retired farmers	Active farmers	Other individuals	Other agencies
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
East South Central	3,784	3,650	5,619	4,681	2,907	6,158	2,053	2,222	2,231	2,206
Owners	3,062	3,068	2,175	5,581	1,460	4,756	2,015	2,607	1,724	1,238
Tenants	4,722	4,361	9,062	3,500	5,800	7,518	2,130	875	2,700	5,350
West South Central	4,051	3,147	7,627	3,646	4,750	7,278	4,032	2,900	3,614	3,045
Owners	3,001	2,454	7,544	3,212	3,102	7,141	2,722	1,917	2,135	2,645
Tenants	5,054	4,495	7,275	4,081	5,797	7,383	6,827	4,375	4,681	3,356
Mountain	4,403	4,267	7,026	5,019	4,614	7,007	4,142	2,732	3,505	3,793
Owners	3,660	3,868	6,038	4,444	3,060	5,629	3,507	2,425	2,906	2,841
Tenants	6,078	5,770	8,464	6,822	6,348	8,492	4,968	3,470	4,982	5,900
Pacific	6,423	4,549	12,645	8,224	5,396	10,646	4,744	3,541	4,486	9,060
Owners	4,943	4,078	8,218	5,723	4,619	7,659	4,460	3,217	3,328	7,834
Tenants	11,919	6,891	17,643	19,157	8,900	12,934	5,875	7,800	10,505	11,081
United States:										
All tenures	5,205	4,193	8,025	4,584	6,258	10,446	4,741	3,276	4,001	4,309
Owners	3,919	3,660	6,683	3,637	4,413	7,812	4,042	2,506	3,105	3,554
Tenants	7,780	5,701	9,203	7,305	8,208	12,451	6,584	6,341	6,192	5,204
Managers	13,576	7,175	18,611	14,912	7,311	18,611	8,778	6,300	13,557	17,080

When classified by tenure, farms operated by their owners show much smaller average size of loans than do farms operated by tenants or managers. The average mortgage reported on full-owner farms was about $3,900; on tenant-operated farms, $7,800; and on manager farms, more than $13,000. These averages reflect principally differences in the value of the respective classes of farms. The sum of $3,919 reported as the average of individual mortgages secured by land operated by full owners is somewhat below the $4,004 reported by the census of 1925 as the average total indebtedness per farm on full-owner farms. The difference is due in part to a slight decline in the average debt on owner-operated farms during this period and in part to the fact that the average of $3,919 is an average of individual loans including second or other mortgages, whereas the sum of $4,004 represents the average total indebtedness per mortgaged farm. As a whole, the average size of loans for owner, tenant, and manager farms is inverse to the total morgage indebtedness of these classes.

Marked variation appears in the size of loans made by the different lenders. Loans from insurance companies averaged largest with $10,400 each, and loans from the joint-stock land banks were next, with approximately $8,000. (Fig. 7 and Table 15.) Mortgage companies held loans averaging over $6,200, commercial-bank mortgages averaged nearly $4,600, and Federal land-bank loans averaged nearly $4,200. Among individual holders, largest loans were from retired farmers whose mortgages averaged $4,700, whereas loans from active farmers were smallest of all with an average of $3,276. Loans held by individuals represent sums more commonly within the range of available funds held by that group. The larger size of loans held by retired farmers, in many cases, reflects purchase-money mortgages received upon sale of farms. Loans held by active farmers

include fewer of this type, and their size as well as their small number seem to indicate limited advances in this form.

Table 15 shows that this relative size of loans held by the various lending agencies also tends to hold true for each of the forms of tenure and in the several geographic divisions. Since the loans of the Federal system are all made on the amortization basis, the average of loans outstanding as reported here will be somewhat less than the average size of the same loans when first made. A decided preference for the larger loans is apparent from the size of holdings of the insurance companies, joint-stock land banks, and farm-mortgage companies. The legal limitations on amount and tenure requirements for the Federal land banks are partly responsible for the smaller size of mortgages held by those institutions.

Restriction of Federal land-bank loans to farms operated by their owners partly accounts for the small size of loans made by those institutions. Since the relative size of the average outstanding loan of the Federal land banks has been about $4,200 as compared with $8,000 for joint-stock land banks, and $10,400 for insurance companies, the handling cost per dollar loaned is affected proportionately.

That larger loans would result if the Federal land banks were permitted to accomodate larger borrowers was indicated by the increase in the size of the average loan made after the amendment of 1923, which raised the maximum loan permitted from $10,000 to $25,000. During the six years of operation under the smaller loan limit, 1917 to 1922, loans averaged $2,943, and during the six years following the amendment, 1924 to 1929, loans averaged $3,525, notwithstanding the lower price levels then prevailing.

PROPORTIONS OF LENDERS' HOLDINGS ON OWNER AND TENANT FARMS

A distribution of mortgages by tenure of the land forming the security shows important differences between holdings of the various classes of lending agencies.[7] (Table 16.) In comparison with an average of 58.7 per cent of mortgage debt on owner-operated farms in 1928 and 41.3 per cent on tenant and manager operated land (see Table 4), mortgage companies and insurance companies have over half of their total loans on lands not occupied by the owners. Joint-stock land banks have the next largest proportion of loans on tenant-operated farms, with a total of 44 per cent for tenant and manager farms together. Commercial banks have approximately one-third, or 33 per cent, of their loans on tenant and manager farms, and the Federal land banks had about 30 per cent on land of these tenures. Among the individual lenders, each of the three classes appears to hold about the same proportion of loans on tenant and manager farms, and 64 to 69 per cent on owner-operated farms.

[7] The method of computing proportions of lenders' holdings secured by owner farms and by others was as follows: The percentage of the total amount of debt reported as secured by mortgage on full-owner farms in each geographic division was calculated for each of nine principal lending agencies. Similar percentages were calculated for tenant and manager operated farms. The percentages found were applied to the total estimated farm-mortgage debt of each corresponding type of tenure in each geographic division. The result represented the total amount of mortgage holdings of each lending agency which was secured by land of each tenure form, in each geographic division. The loans of each agency on farms of all tenure groups within each geographic division were added to obtain the total loans held in that division by such lending agency. With the total holdings of each agency in each geographic division taken as 100, the debt secured by farms of each form of tenure was expressed as a percentage of the total in that division. The percentage of the total mortgage debt of the country represented by debt on farms of each principal tenure form was computed as follows: The farm-mortgage holdings for each tenure in all geographic divisions were added, and the resulting sum was divided by the total mortgage debt of the division as estimated for 1928.

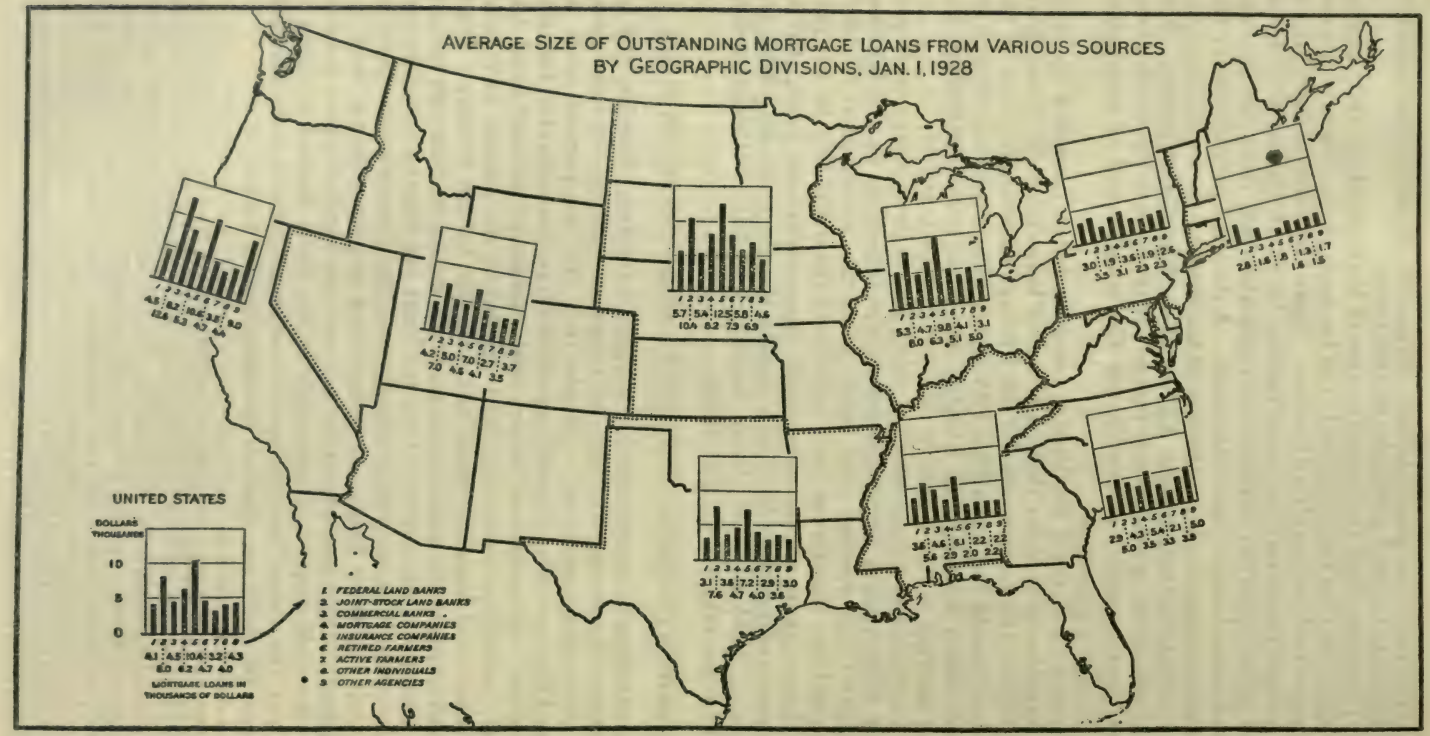

FIGURE 7.—A comparison of average size of loans held by lending agencies shows the insurance companies and joint-stock land banks to have much larger loans than others, though loans from banks are nearly as large in the Pacific division. Loans from all agencies average large in the North Central divisions and small in the North Atlantic

TABLE 16.—*Distribution of farm-mortgage holdings of principal lending agencies by tenure of land mortgaged, in geographic divisions, 1928*

Geographic division and tenure	Total		Holdings of principal agencies								
	Debt	Per cent of debt on farms of each tenure	Federal land banks	Joint stock land banks	Commercial banks	Mortgage companies	Insurance companies	Retired farmers	Active farmers	Other individuals	Other agencies
	1,000 dollars	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
New England	122,494	100.0	100.0	-------	100.0	-------	100.0	100.0	100.0	100.0	100.0
Owners	112,315	91.7	98.1	-------	92.4	-------	100.0	95.9	78.2	92.3	81.6
Tenants and managers	10,179	8.3	1.9	-------	7.6	-------	-------	4.1	21.8	7.7	18.4
Middle Atlantic	376,614	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Owners	291,570	77.4	76.3	60.5	75.5	46.1	33.7	82.9	93.2	81.3	48.8
Tenants and managers	85,044	22.6	23.7	39.5	24.5	53.9	66.3	17.1	6.8	18.7	51.2
East North Central	1,950,126	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Owners	1,220,276	62.6	60.6	56.0	73.7	49.5	44.5	77.4	66.7	74.9	66.7
Tenants and managers	729,850	37.4	39.4	44.0	26.3	50.5	55.5	22.6	33.3	25.1	33.3
West North Central	4,056,187	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Owners	2,178,998	53.7	75.6	64.6	53.3	46.7	43.0	64.0	51.7	56.7	55.4
Tenants and managers	1,877,189	46.3	24.4	35.4	46.7	53.3	57.0	36.0	48.3	43.3	44.6
South Atlantic	491,896	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Owners	280,163	57.0	66.3	37.7	70.6	23.9	33.4	41.1	60.6	61.6	58.6
Tenants and managers	211,733	43.0	33.7	62.3	29.4	76.1	66.6	58.9	39.4	38.4	41.4
East South Central	381,497	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Owners	239,725	62.8	63.4	32.4	80.7	50.6	55.2	79.2	95.1	54.1	60.1
Tenants and managers	141,772	37.2	36.6	67.6	19.3	49.4	44.8	20.8	4.9	45.9	39.9
West South Central	901,252	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Owners	453,965	50.4	63.6	48.8	56.3	35.5	54.7	58.4	51.6	43.9	50.2
Tenants and managers	447,287	49.6	36.4	51.2	43.7	64.5	45.3	41.6	48.4	56.1	49.8
Mountain	496,551	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Owners	294,116	59.2	71.7	52.0	65.1	40.3	42.2	49.9	63.2	62.8	51.7
Tenants and managers	202,435	40.8	28.3	48.0	34.9	59.7	57.8	50.1	36.8	37.2	48.3
Pacific	691,909	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Owners	488,889	70.7	83.5	53.1	66.5	74.3	51.5	85.9	88.6	70.7	74.4
Tenants and managers	203,020	29.3	16.5	46.9	33.5	25.7	48.5	14.1	11.4	29.3	25.6
United States	9,468,526	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Owners	5,560,017	58.7	70.2	56.2	67.1	45.1	44.7	69.2	65.8	64.4	59.9
Tenants	3,644,009	38.5	28.0	40.2	29.6	52.5	53.0	28.9	32.8	31.9	35.2
Managers	264,500	2.8	1.8	3.6	3.3	2.4	2.3	1.9	1.4	3.7	4.9

This varying distribution of mortgage holdings by tenure has its principal significance in its relation to loaning policies of the different agencies and the differences as a loan market which the respective tenures offer. In general, the insurance companies, mortgage companies, and the joint-stock land banks have made loans of larger amounts, whereby in a single transaction a considerable sum can be invested with practically no extra cost or inconvenience. This partly accounts for the dominance of loans from these agencies on the larger properties represented by manager farms in all divisions and by tenant-operated farms in all divisions except those in the South. Even in the Southern States the relatively small acreages operated by individual tenants often are parts of larger tracts which are owned by one individual and which may provide the security base for large and more economical loans. (See tabulation on p. 100.)

The case of the Federal land banks calls for particular consideration in view of the requirement of the Federal farm loan act that "no such loan shall be made to any person who is not at the time, or shortly to become, engaged in the cultivation of the farm mortgaged" (*24, sec. 12*).[8] Despite the smaller size of loans which this provision makes necessary for the Federal banks, the loans on owner farms equal only 70 per cent of the total.

There remains 28 per cent of the loans of Federal land banks secured by lands operated by tenants, as classified by the census. But the great part of this sum is probably secured by land that was operated by owners when the loans were made but has since become tenant-operated land. The tenure classification of farms as used here was that existing January 1, 1925. Inasmuch as only those farms which had changed neither ownership nor tenure from 1925 to 1928 were used in this analysis, it appears that within the space of eight years (1917 to 1925) 28 per cent of the funds loaned by this agency to owner operators became secured by tenant-operated lands, and about 2 per cent by manager farms. This raises the question as to the value of personal and tenure requirements as a provision of long-term loans. The continued change of ownership and tenure has an important cumulative effect over a period of years.

PERCENTAGE OF FARMS MORTGAGED

The volume of fixed debt on farms at any given time may be said to be the result of the two ratios—percentage of farms mortgaged, and the proportion of the farm value covered by the debt. Of these two factors, the percentage of farms mortgaged has been much the more stable. It has shown a uniform rate of increase over a long period. The owner-operated farms reported as mortgaged in the country as a whole have ranged from 27.8 per cent in 1890 to 37.2 per cent in 1920. After a slight decline reported by the census of 1925 (*20*), farms reporting in 1928 indicated a continuation of the rising trend which had been in progress since 1890. (Fig. 8.) This slow but rather constant increase in the number of mortgaged farms amounting to 10 per cent of all owner farms over a span of 38 years, including the period of active land movement between 1910 and 1920,

[8] This provision of the act is supplemented by the following ruling: "An actual farmer is one who conducts the farm and directs its entire operation, cultivating it with his own hands or by means of hired labor. An owner must be responsible in every way, financially and otherwise, for the cultivation of the land, to borrow from a Federal land bank under the Act" (*24, sec. 45*).

suggests that the number of farms under mortgage is not likely to undergo any considerable change within a short period.

The relatively small proportion of 27.8 per cent of owner farms reporting debt in 1890 reflected in part the ownership of farms that had been acquired by homestead rather than by purchase. The low percentage of mortgage also reflected a prevailing low price of farm land and the consequent small amount of capital required for land purchase. It is probable, however, that even the percentage then reported was a material increase over the number of farms with mortgage in the preceding years, inasmuch as that period had witnessed a great influx of funds loaned on mortgage of mid-western agricultural lands. During the two decades following 1890 the percentage of farms mortgaged rose to 30 in 1900 and 33.2 in 1910, both figures showing some relationship to the rising prices of the period. The greater sums involved in the purchase of farm lands

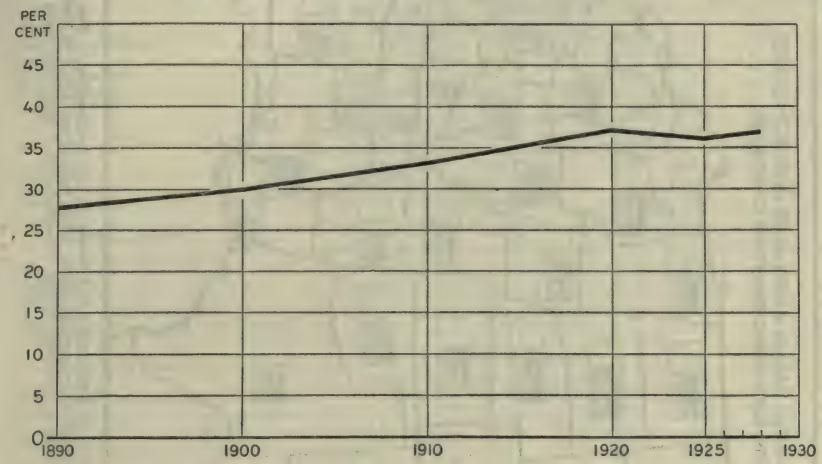

FIGURE 8.—PERCENTAGE OF OWNER FARMS MORTGAGED

The percentage of owner-operated farms with mortgage debt has followed a steady upward trend since 1890. In 1890 the percentage of farms mortgaged was 27.8; in 1920 the corresponding figure was 37.2. Recent data indicate the continuation of the rise at slightly more than the long-term rate of about 0.25 per cent a year.

resulted in a growing recourse to mortgage credit as a means of settlement.

During the years 1910 to 1920, when land prices were rising rapidly and many sales of land occurred, the percentage of farms mortgaged increased from 33.2 per cent to 37.2 per cent, approximately at the same rate as in each of the two previous decades, although the total amount of mortgage debt more than doubled. Again, during the five years, 1920 to 1925, a period of depression in agriculture when the debt increased nearly one-fifth over 1920, the percentage of mortgaged farms remained almost constant, the census of 1925 showing 36.1 per cent of owner farms encumbered.[9] This slight decline reflects in part the cancellation of many mortgages in western areas caused by reversion of farms to former owners.

[9] The lower percentage for 1925 may have been due in part to the form in which this question was asked by the 1925 census schedules. Whereas the 1920 census carried one inquiry as to the existence of debt and another asking the amount of debt, the 1925 census asked only the amount. Enumerators sometimes are able to obtain information as to the first but not the second item. In 1920 this class of reports constituted 0.61 per cent of all farms. The 1925 census did not give the number not reporting on debt.

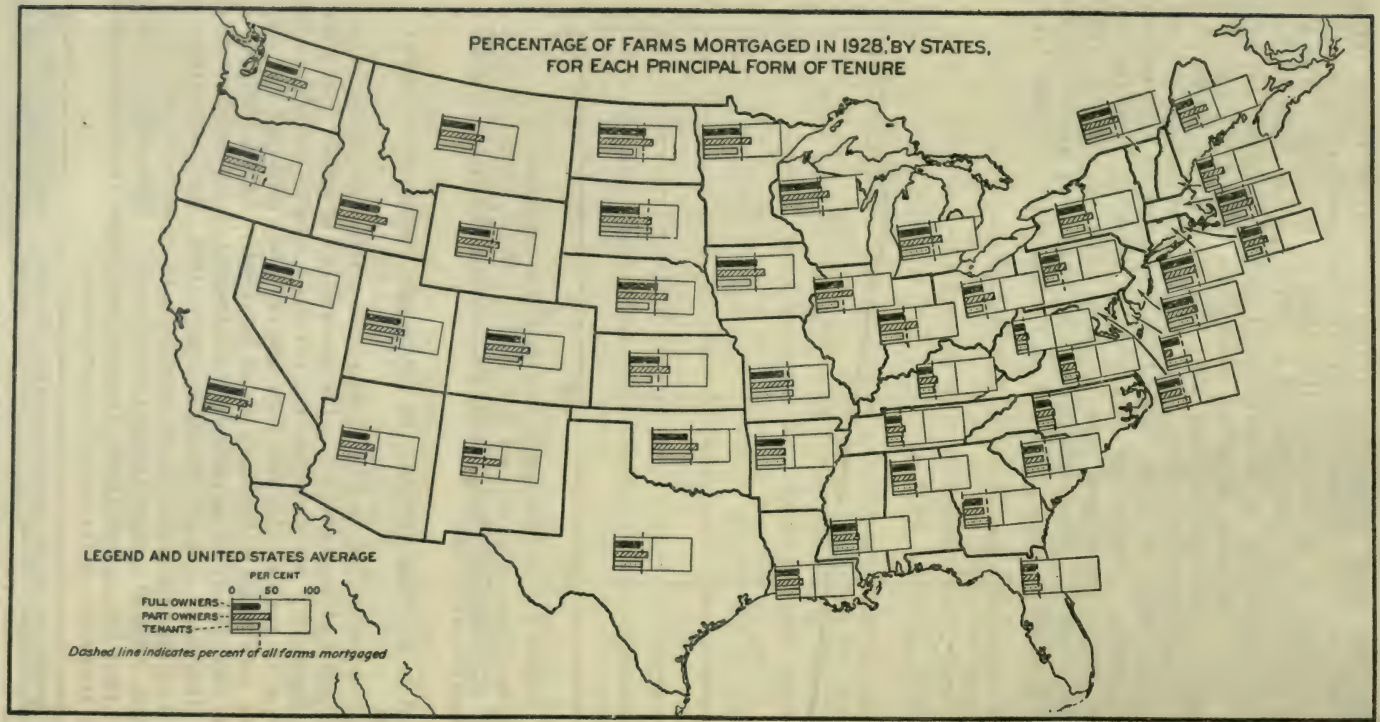

FIGURE 9.—The percentage of farms mortgaged is highest in the North Central States and lowest in the Southeastern. For the country as a whole and in most of the States, owner-operated farms are mortgaged in more cases than are tenant-operated farms, while part-owner farms in 1925 reported indebtedness on the land in 42 per cent more cases than for full-owner operated farms. In a number of Southern States tenant-operated farms are more frequently under mortgage than are farms operated by their owners

During the period 1925 to 1928 the percentage of all farms having mortgage, inclusive of all tenures, increased from 34.8 to 36. (Fig. 9 and Table 17.) Increases occurred for all forms of tenure and for all geographic divisions save the Mountain division and New England. Although most of the divisions had individual States in which declines were indicated, the dominant tendency was toward an increase in the use of farms as security for loans.

TABLE 17.—*Frequency of mortgage debt on all farms in the United States, and on farms operated by full owners, part owners, and tenants, by States and geographic divisions, January 1, 1925, and 1928*

State and geographic division	All farms [1]		Full owner-operated farms		Part owner-operated farms		Tenant-operated farms	
	1925	1928	1925 [2]	1928	1925 [2]	1928	1925	1928
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Maine	24.6	23.9	24.6	23.8	39.9	38.6	20.2	20.4
New Hampshire	23.3	21.8	23.5	21.9	33.3	31.0	19.3	19.5
Vermont	42.7	43.0	43.4	43.8	49.8	50.2	35.7	36.0
Massachusetts	38.8	38.4	39.4	39.0	46.1	45.6	32.4	32.7
Rhode Island	27.6	27.8	28.7	28.9	33.5	33.8	23.6	23.8
Connecticut	42.2	42.6	42.9	43.3	47.9	48.3	35.3	35.6
New England	33.2	32.8	33.3	33.6	44.5	44.3	27.4	27.6
New York	37.5	37.2	38.2	37.6	45.7	45.1	30.5	31.0
New Jersey	39.8	38.8	41.1	39.6	44.5	43.1	32.8	33.2
Pennsylvania	22.8	24.2	23.5	25.1	29.3	31.4	18.8	19.1
Middle Atlantic	30.7	31.1	31.4	31.8	40.3	40.5	25.1	25.5
Ohio	24.8	26.4	25.2	26.4	37.3	39.6	19.8	22.7
Indiana	34.6	35.4	33.9	34.8	48.7	50.6	30.1	30.3
Illinois	34.9	35.3	32.6	36.4	44.0	49.7	33.8	29.1
Michigan	43.3	43.5	42.4	43.0	53.9	55.3	40.2	37.7
Wisconsin	53.8	54.3	55.3	54.5	63.4	63.1	41.6	49.0
East North Central	37.5	38.3	38.2	39.2	47.8	50.1	31.4	34.0
Minnesota	47.6	48.5	46.2	47.4	60.2	61.6	44.8	44.6
Iowa	50.1	50.5	53.7	53.1	63.3	62.4	43.1	44.7
Missouri	46.3	48.7	42.0	43.8	53.6	55.7	50.6	54.3
North Dakota	57.8	58.8	59.2	60.7	69.1	70.7	46.4	46.2
South Dakota	63.1	61.4	54.6	50.5	71.5	66.0	63.9	66.6
Nebraska	48.1	50.3	52.0	52.2	65.8	65.8	38.3	42.7
Kansas	39.1	37.8	41.0	38.2	56.7	52.6	28.8	30.1
West North Central	48.4	49.2	47.3	47.6	61.9	61.2	43.5	45.6
Delaware	28.3	27.6	27.3	24.2	12.8	11.8	30.7	34.4
Maryland	31.7	32.9	30.0	30.5	28.9	29.8	33.7	37.8
District of Columbia	31.7	32.9	21.6	30.5	42.9	29.8	24.3	27.3
Virginia	19.6	20.1	18.7	18.5	20.8	21.0	21.0	23.7
West Virginia	12.5	15.0	12.0	14.7	14.7	18.4	13.5	15.4
North Carolina	20.1	22.5	18.8	20.8	22.2	25.1	21.1	23.9
South Carolina	28.2	31.0	26.1	27.5	24.5	26.3	29.3	32.9
Georgia	29.6	31.5	27.2	26.2	27.2	26.7	30.6	34.3
Florida	20.4	20.7	19.3	19.2	22.7	23.0	21.7	24.5
South Atlantic	23.4	25.2	20.6	21.4	22.4	23.5	23.2	26.1
Kentucky	19.3	20.5	19.2	20.3	24.0	25.6	18.2	19.6
Tennessee	20.0	21.1	20.1	21.0	24.3	25.6	19.0	20.5
Alabama	28.9	30.5	29.8	30.6	30.2	31.3	28.2	30.3
Mississippi	31.9	33.7	33.0	33.9	34.8	36.0	31.2	33.5
East South Central	25.0	26.4	23.7	24.7	26.6	27.7	22.4	24.1
Arkansas	33.7	36.7	32.5	34.9	35.4	38.0	34.3	37.8
Louisiana	28.2	30.8	27.0	29.3	32.8	35.6	28.5	31.4
Oklahoma	47.9	50.7	45.0	45.3	58.1	58.5	47.5	52.2
Texas	34.2	36.8	32.5	33.8	42.4	44.1	34.3	37.8
West South Central	36.0	38.7	33.9	35.5	45.2	46.7	35.8	39.4

[1] Includes manager-operated farms.
[2] Derived from census reports of 1925 (*20*).

TABLE 17.—*Frequency of mortgage debt on all farms in the United States, and on farms operated by full owners, part owners, and tenants, by States and geographic divisions, January 1, 1925, and 1928*—Continued

State and geographic division	All farms		Full owner-operated farms		Part owner-operated farms		Tenant-operated farms	
	1925	1928	1925	1928	1925	1928	1925	1928
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Montana	53.0	49.0	49.3	44.8	64.9	58.9	48.0	46.5
Idaho	53.5	52.2	52.1	50.6	67.0	65.0	50.7	49.2
Wyoming	47.7	45.6	43.8	41.6	57.9	55.0	42.6	41.3
Colorado	51.4	48.4	49.3	45.7	64.1	59.3	48.0	46.5
New Mexico	25.6	27.6	22.5	24.6	45.1	49.3	21.9	21.2
Arizona	39.1	36.1	38.0	34.2	51.0	45.9	37.0	35.8
Utah	43.9	45.0	42.6	43.9	51.8	53.3	41.5	40.2
Nevada	33.6	36.3	32.9	35.9	45.3	49.4	32.0	31.0
Mountain	46.6	45.0	43.4	41.8	60.3	57.3	42.2	41.0
Washington	43.3	42.8	43.8	42.7	60.3	58.9	32.1	33.7
Oregon	43.4	44.2	44.1	44.5	56.0	56.7	32.3	34.0
California	44.0	46.5	45.8	47.8	53.0	55.5	33.6	35.3
Pacific	43.7	45.0	44.9	45.8	56.2	56.8	32.9	34.6
United States	34.8	36.0	34.0	34.7	48.1	48.5	32.5	34.8

DEBT DIFFERENCES BETWEEN FORMS OF TENURE

The percentage of owner-operated farms mortgaged changed only slightly during the years 1925 to 1928, but frequency of mortgage on tenant and manager operated farms showed a pronounced rise from 32.5 to 34.8 per cent—approximately equal to that on full-owner farms. In most of the principal divisions the percentage of mortgaged tenant farms remained below that for owner farms. This was especially marked in the North Atlantic and Pacific divisions. The South Atlantic and West South Central divisions reported larger percentages of the tenant farms mortgaged than of full-owner farms and the East South Central and Mountain divisions had nearly equal proportions.

The greater average size and value of tenant and manager operated farms have made them a more ready security basis for commanding credit on favorable terms. Full-owner farms averaged 127 acres in 1925, tenant farms comprised 108 acres, and manager farms 1,059 acres. (Table 46.) Manager farms reported debt for nearly one-half of all such farms reported. Although this class of properties often have some land-secured debt, especially if operated for commercial purposes rather than as a country residence only, the amount of the mortgage usually constitutes a lower percentage of the value of the farm.

A classification of tenant and manager operated farms on the basis of type of ownership indicates that farms owned by active farmers operating elsewhere are much more often encumbered than are tenant and manager farms owned by nonfarming classes. Of 5,719 tenant and manager farms that reported in 1928 on the existence of mortgage debt, 45.9 per cent of those owned by active farmers were mortgaged as compared with 35.9 per cent of such farms owned by nonfarmers. (Table 18.) In the North Central States these proportions averaged 58 and 40 per cent, respectively. The less frequent debt on land owned by nonfarmers is doubtless due in part

to the fact that owners not operating their own farms more often have incomes from sources other than agriculture, hence are less often in need of borrowing on the security of farm lands.

TABLE 18.—*Percentage of tenant-operated farms* [1] *reporting mortgage debt, by type of ownership*

Geographic division	Tenant farms reporting		Tenant farms reporting mortgage in 1928	
	Owned by active farmers	Owned by non-farmers	Owned by active farmers	Owned by non-farmers
	Number	*Number*	*Per cent*	*Per cent*
New England	25	82	16.0	23.2
Middle Atlantic	87	295	36.8	23.7
East North Central	159	574	60.4	36.6
West North Central	334	1,280	56.3	43.7
South Atlantic	339	469	33.3	22.4
East South Central	232	266	34.9	19.9
West South Central	255	413	51.4	45.8
Mountain	123	316	54.5	44.9
Pacific	118	352	46.6	30.1
United States	1,672	4,047	45.9	35.9

[1] Includes manager farms.

Part-owner farms, which constitute nearly one-third of all farm land operated by farm owners, carry mortgages on the owned land in a much higher percentage of cases than do farms operated by either full owners or tenants Part owners are farmers who operate some land which they own, together with additional land which they rent. Over 48 per cent of all farms of this class reported mortgages in 1925 as compared with 34 per cent of full-owner farms. (Table 17.) The more frequent use of mortgage credit by this class of farms probably is explained by greater need for capital occasioned by the operation of the additional land that the part-owner rents from others. This acreage of rented land in part-owner farms is approximately equal to the area owned. Provision for the stock, equipment, and current expense necessary for the entire farm thus induces borrowing on the owned acreage in a higher percentage of instances than on fully owned farms.

CHANGE IN DEBT FREQUENCY ON FARMS HAVING THE SAME OWNERSHIP

Most of the increase in the number of farms mortgaged between 1925 and 1928 occurred on farms having the same ownership throughout the period. Only a slight net increase was reported for those farms that had been transferred to new owners. New mortgages were reported as most frequent in the West South Central division, where 2 per cent of all the farms had them and were least important in New England, where farms with new mortgages were less than 1 per cent of all farms. In all other divisions the rate of incurring debt ranged from about 1 to 1.5 per cent or an average of slightly less than 0.5 per cent per year for the 3-year period. (Table 19.)

TABLE 19.—*Annual rates at which nonmortgaged farms became mortgaged, and mortgaged farms were cleared of debt, 1925–1928*

Geographic division	Change, of all farms			Change, of all farms mortgaged		
	Nonmortgaged farms incurring mortgage	Mortgaged farms cleared of debt	Increase or decrease in farms mortgaged	Nonmortgaged farms incurring mortgage	Mortgaged farms cleared of debt	Increase or decrease in farms mortgaged
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
New England	0.86	1.00	−.14	2.62	3.04	−0.42
Middle Atlantic	1.15	.97	.18	3.70	3.12	.58
East North Central	1.32	.89	.43	3.45	2.32	1.12
West North Central	1.22	.95	.27	2.48	1.93	.55
South Atlantic	1.54	1.12	.42	5.92	4.30	1.62
East South Central	1.38	.98	.40	5.23	3.71	1.52
West South Central	2.04	1.14	.90	5.27	2.94	2.33
Mountain	1.29	1.38	−.09	2.86	3.06	−.20
Pacific	1.59	1.23	.36	3.53	2.73	.80
United States	1.45	1.03	.42	4.04	2.86	1.18

When expressed as a percentage of farms mortgaged, the number of new mortgages incurred on farms not previously encumbered amounted to more than 4 per cent of the total farms bearing mortgage. Expressed in these terms, the variation among the geographic divisions was greater; the new farms mortgaged ranged from about 2.5 per cent of all mortgaged farms in the West North Central to nearly 6 per cent in the South Atlantic division.

FREQUENCY OF DEBT ON TRANSFERRED FARMS

Reports on farms transferred to other owners between 1925 and 1928 indicate that on the average such farms had mortgages in about three-fourths of all cases, or almost exactly twice the frequency of debt on all farms. The number of farms reported as being mortgaged before transfer was nearly as large as the number with debt after transfer, that is, 72.4 per cent as compared with 75.1 per cent. (Table 20.) Pressure of debt doubtless has been an important influence in bringing about transfers of indebted farms, and financing of transfers frequently includes use of a mortgage on land acquired.

TABLE 20.—*Annual rates of increase or decrease in number of transferred farms which were mortgaged,*[1] *1925 and 1928*

Geographic division	Percentage of transferred farms 1925–1928 having mortgage debt			Farms reported to have changed hands	
	1925 before transfer	1928 after transfer	Increase or decrease from 1925 to 1928	Total	3-year average increase or decrease in transferred farms
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
New England	67.8	67.8	0	7.8	0
Middle Atlantic	64.9	65.9	1.0	6.9	.02
East North Central	73.8	78.4	4.6	9.1	.14
West North Central	84.3	83.0	−1.3	9.8	−.04
South Atlantic	64.8	69.9	5.1	14.0	.24
East South Central	65.7	68.2	2.5	11.8	.10
West South Central	76.7	80.1	3.4	12.7	.14
Mountain	76.7	76.4	−.3	15.3	−.02
Pacific	78.8	79.7	.9	9.2	.03
United States	72.4	75.1	2.7	11.1	.10

[1] United States figures weighted by number of farms.

The uniformity among these reports of debt frequency among farms changing hands is striking evidence of the important part that mortgage credit has in the purchase and sale of farm real estate. Among the geographic divisions, this percentage of farms mortgaged after transfer varied from 66 to 83 per cent, tending toward larger proportions in the areas of high land value. High as these figures are, they still remain less than the frequency of morgtage on farms transferred during the land boom. Of 927 land sales in Iowa in 1919, 90 per cent involved mortgages (*10*).

METHOD USED IN COMPUTING PERCENTAGE OF FARMS MORTGAGED

The frequency of mortgage debt on farms operated by full owners and part owners in 1925 in each State and geographic division was found directly from the 1925 census by subtracting the mortgaged part-owner farms from total owner-operated farms mortgaged and computing separate percentages for the two classes. The sample reports for other tenures in 1925 and for all tenures in 1928 were aligned with the 1925 census reports by use of a correction factor computed as follows: The percentage of all full-owner farms reporting mortgage for 1925 on the returned schedules as shown by the county groupings used for each State was divided by the percentage of all full-owner farms reported as mortgaged in the 1925 census report for the same State.

In the absence of data for Connecticut, a weighted group frequency was obtained for the other five New England States. A correction factor obtained by use of 1925 census data for the five States, was applied to the 1928 sample data weighted for the same five States to get a corrected figure for the five States for which sample data were available. The percentage figure of New England for 1928 was then found by use of the following equation:

$$\frac{a}{a^1}=\frac{b}{x},$$

in which

a = percentage of full-owner farms mortgaged in five States, census, 1925.

a^1 = the percentage of full-owner farms mortgaged in six New England States, census, 1925.

b = percentage of full-owner farms mortgaged in five States, sample, 1928.

x = computed percentage of farms mortgaged in New England, 1928.

Frequency figures for owner farms in Vermont, Rhode Island, and Connecticut in 1928 were found by the equation

$$\frac{C}{c}=\frac{D}{x},$$

in which

C = percentage of full-owner farms mortgaged in New England, census, 1925.

c = percentage of full-owner farms mortgaged in the State, census, 1925.

D = computed percentage of full-owner farms mortgaged in New England in 1928.

x = computed percentage of full-owner farms mortgaged in the State in 1928.

The percentage of tenant farms mortgaged in each State of the East and West North Central divisions was computed for 1925 and 1928 by dividing the average frequency for each State as reported on the schedules for 1925 and 1928 by the correction factor referred to above.

Frequency ratios for all owners for 1928 in all States save Vermont, Rhode Island, Connecticut, Montana, and Nevada were found by applying the correction factor, found above, to the State ratios as shown by the schedules for 1928. In Montana and Nevada the frequency of mortgage on full-owner farms was computed by assuming that the 1928 ratio for these States had the same relation to their 1925 ratios as did the geographic-division ratios for the corresponding years. The geographic-division ratio was found by dividing the geographic sample by the correction factor for the same area. Full owners and part owners were treated by the same method.

For tenants other than those in the North Central States, the frequency ratio as shown by the used groupings of schedules in the sample for each State was divided by the State correction factor, and the result multiplied by the number of farms in that State. The sum of the products was divided by the total number of farms of that tenure in the geographic division, thus obtaining a weighted frequency ratio for the geographic division. By using this ratio in the second term of a proportion, the frequency of mortgage tenant and manager operated farms for each State was found by the following equation:

$$\frac{F}{f}=\frac{T}{X}$$

in which

F = full-owner geographic frequency of mortgage, census 1925.
f = full-owner State frequency of mortgage, census 1925.
T = tenant (manager) geographic frequency of mortgage 1925 (1928) (computed).
X = tenant (manager) frequency of mortgage for State 1925 (1928).

Frequency ratios for manager farms were grouped into five main groups as described elsewhere. (See methods of estimate, p. 12.) The 1925 sample for the geographic division treated with the correction factor for the same division was weighted with the number of manager farms in the division, and a corrected frequency was found for each of the five main groups. This corrected and combined frequency was used for each geographic division included in the group in finding the percentage of manager farms mortgaged in each State.

The equation used is as follows:

$$\frac{F}{f}=\frac{M}{X}$$

in which

F = 1925 full-owner census group frequency.
f = 1925 full-owner census State frequency.
M = 1925 group manager frequency.
X = 1925 State manager frequency.

The frequencies for 1928 were computed in the same way.

Frequency of debt for 1928 was adjusted for data on transferred farms as follows: The number of farms transferred in each geographic division from 1925 to 1928, estimated as a percentage of all farms, was multiplied first by the percentages estimated as mortgaged in 1925 and in 1928. The difference between these two products was used as representing the increase or decrease in percentage of all transferred farms mortgaged in the geographic division concerned. This increase or decrease, a small fractional difference in most cases, was added to, or subtracted from, the frequency of each State computed for 1928 as described above, to obtain a final frequency of farms mortgaged as of January 1, 1928.

RATIO OF DEBT TO VALUE OF FARMS

The percentage that fixed debt bears to the value of farms is both the most significant feature of mortgage debt and the most variable. Tending to rise when land values fall and to fall when land values rise, this ratio of debt to value of farms has followed an irregular but generally upward course, both for individual farms and for agriculture as a whole. During the period 1920 to 1928 both factors of land values and farm-mortgage debt were tending to increase the debt to value ratio and consequently tending to reduce the owner's equity. Of these two factors the change in land values was the more important. The index of land values, which in 1920 had risen to 170 from a 1912–1914 base of 100, by 1925 had declined to 127, and in 1928 stood at 117. During the same period the total mortgage debt had increased 20 per cent over that of 1920.

RATIO OF MORTGAGE INDEBTEDNESS TO VALUE OF ALL FARMS 1910 TO 1928

Just as the ratio of debt to value of a given farm measures the encumbrance and equity of a particular property so the relation of total debt and total value of all the farms may be taken to indicate the burden of debt upon the agriculture of the State or area as a whole. The ratio of debt to value of all agricultural land and buildings for the country rose from 9.5 in 1910 to 11.8 in 1920, to 18.9 in 1925, to 21 in 1928. (Table 21.) The slight increase in the ratio of 2.3 between 1910 and 1920 despite an increase in the debt of 136 per cent was mainly due to the nearly equal rise in land values. A reverse in the trend of land values in 1920 amounting to a 30 per cent decrease in the value of land, by 1928,[10] and a simultaneous increase of 20 per cent in debt nearly doubled the debt ratio by 1928. Further evidence that the rise in the ratio of debt to value during that period was due mostly to changes in the value of land is seen in the fact that the most marked changes appeared where land values underwent the greatest downward revision. During the three years prior to 1928 increases occurred in seven of the nine geographic divisions, but New England and the Middle Atlantic States showed slight declines.

[10] Computed from Department Circular 60 (*29, p. 9*).

TABLE 21.—*Ratio of mortgage debt to value of all farms in the United States, by States and geographic divisions, January 1, 1910, 1920, 1925, and 1928*

State and geographic division	Ratio of debt to value of all farms			
	1910	1920	1925	1928
	Per cent	*Per cent*	*Per cent*	*Per cent*
Maine	8.3	10.2	13.2	12.8
New Hampshire	6.8	9.6	8.9	8.9
Vermont	14.1	18.2	20.4	21.0
Massachusetts	11.8	13.8	12.6	12.4
Rhode Island	7.9	8.9	8.7	8.4
Connecticut	11.6	13.6	13.5	13.4
New England	10.6	13.2	13.7	13.5
New York	13.0	15.7	16.6	16.8
New Jersey	14.6	15.8	15.9	15.0
Pennsylvania	9.2	10.0	10.3	10.2
Middle Atlantic	11.5	13.2	13.9	13.9
Ohio	6.8	7.9	11.0	13.1
Indiana	7.0	7.8	15.6	19.9
Illinois	7.6	8.4	15.5	19.5
Michigan	12.2	15.0	17.8	19.5
Wisconsin	16.1	20.8	26.6	30.2
East North Central	9.0	10.7	16.9	20.4
Minnesota	11.6	13.8	23.1	26.5
Iowa	13.2	14.5	28.7	32.9
Missouri	11.8	12.6	22.4	26.1
North Dakota	12.3	18.0	22.2	24.8
South Dakota	8.8	11.3	25.9	30.9
Nebraska	8.9	11.2	24.5	25.0
Kansas	9.4	10.4	22.0	20.7
West North Central	11.2	13.1	25.0	27.5
Delaware	12.2	13.9	14.6	16.0
Maryland	12.2	12.7	14.8	17.0
District of Columbia	3.5	6.1	6.3	7.8
Virginia	4.5	6.0	9.0	11.0
West Virginia	3.1	3.9	5.2	6.2
North Carolina	4.2	5.3	8.5	10.5
South Carolina	6.2	6.3	15.0	21.2
Georgia	6.0	7.4	18.6	23.9
Florida	3.7	7.0	5.3	5.8
South Atlantic	5.7	6.7	10.7	13.2
Kentucky	6.4	8.0	11.2	13.2
Tennessee	5.6	8.1	11.3	13.7
Alabama	8.6	10.2	16.0	17.8
Mississippi	9.4	9.8	23.6	26.9
East South Central	7.1	8.7	14.4	16.6
Arkansas	7.2	10.2	18.1	20.8
Louisiana	8.0	8.7	17.8	20.3
Oklahoma	10.5	13.8	20.9	22.5
Texas	9.3	10.7	15.9	17.5
West South Central	9.3	11.2	17.3	19.1
Montana	7.8	20.0	25.6	24.3
Idaho	9.9	19.8	28.8	28.4
Wyoming	8.0	14.0	25.1	24.9
Colorado	10.2	16.0	25.9	27.4
New Mexico	4.3	10.7	16.5	15.4
Arizona	10.3	18.4	20.5	20.0
Utah	6.1	14.6	20.4	19.4
Nevada	8.4	17.9	22.4	21.2
Mountain	8.6	17.2	24.6	24.2
Washington	7.9	12.7	16.7	17.0
Oregon	7.7	13.5	17.1	18.7
California	8.4	13.8	14.0	14.9
Pacific	8.2	13.6	14.9	15.7
United States	9.5	11.8	18.9	21.0

In the New England and Middle Atlantic States the ratio of debt to value of all land has remained nearly constant having been 10.6 in New England in 1910 and slightly more than 13 per cent in 1920, 1925, and 1928. During the same period the corresponding ratio for the Middle Atlantic States rose from 11.5 to 13.9. Land values in these divisions rose less than those elsewhere in the years prior to 1920, hence the subsequent decline has been more moderate and has been accompanied by some reduction in mortgage debt.

The most significant changes in the ratio of debt to value of all land appear in the North Central States, where the ratio of the eastern division rose from 9 in 1910 to 10.7 in 1920, to 16.9 in 1925, and to 20.4 in 1928, more than doubling the ratios in 18 years. The western division increased from 11.2 in 1910 to 27.5 in 1928. The South Atlantic States increased their ratio from 5.7 in 1910 to 13.2 in 1928, and the ratio for the East South Central States rose from 7.1 in 1910 to 16.6 in 1928. In all these divisions the rising debt ratios since 1920 were the combined result of severe declines in land values and substantial increases in the mortgage debt. In general these divisions comprise much of the territory in which the Federal land banks and joint-stock land banks have expanded their loan operations.

Three western divisions showed much less change. In the West South Central division the ratio of debt to value of all land rose from 9.3 in 1910, to 11.2 in 1920, to 17.3 in 1925, and to 19.1 in 1928. Here the rise since 1920 was less marked, despite steady increases in debt, on account of the well-sustained value of land in Texas and in Oklahoma. The sharp rise in the debt ratio in the Mountain States from 8.6 to 17.2 during the development of that region between 1910 and 1920 was followed by a moderate rise to 24.6 in 1925, and a slight decline to 24.2 in 1928, largely the result of substantial reduction in indebtedness incident to foreclosure and reversion of title. The debt ratio for the Pacific Coast States rose from 8.2 to 13.6 in the 10 years before 1920. Thereafter it displayed an even rise to 14.9 in 1925 to 15.7 in 1928, the increase in indebtedness having been nearly offset by the well-sustained land values in those States.

RATIO OF DEBT TO VALUE OF MORTGAGED FARMS

A greater variation from one date to another appears in the ratios of debt to value of the farms that are mortgaged than for farm land as a whole.

The ratio of debt to value of mortgaged full-owner farms which in 1890 was 35.5 became 27.3 in 1910, and 29.1 at the peak of land values in 1920. The marked decline in land values after 1920 accompanied by the increase in mortgage debt had the net result of raising the debt ratio of mortgaged farms to 41.9 in 1925, with a further rise to 46 in 1928. (Fig. 10 and Table 22.)

TABLE 22.—*Ratio of debt to value of full-owner operated farms, 1925*[1] *and 1928*

Geographic division	Ratio of debt to value		Geographic division	Ratio of debt to value	
	1925	1928		1925	1928
	Per cent	*Per cent*		*Per cent*	*Per cent*
New England	40.1	40.7	West South Central	37.4	41.3
Middle Atlantic	41.1	41.3	Mountain	43.2	42.1
East North Central	44.2	52.6	Pacific	34.9	35.2
West North Central	44.9	49.3			
South Atlantic	37.1	44.0	United States	41.9	46.0
East South Central	41.9	48.6			

[1] Census.

The rise of the average of debt ratios to a point approaching 50 per cent of the value of the land had grave significance for many farmers who had loans to renew. A general policy of limiting farm mortgages to amounts representing about one-half of the value of the farm had long been in effect among important lenders on farm real estate. This situation resulted in wide differences in the opportunity for refinancing.

It would appear that the falling land values and the rising debt of recent years did not affect the ratio of debt to value of all tenures in equal degree, although the upward trend was common to all. Full-owner farms, which had a higher debt ratio in 1925 than had tenant farms, maintained a higher ratio in 1928. When farms under mortgage in both 1925 and 1928 are considered separately, it is found that both the tenant-operated and the manager-operated farms in this group increased their debt burden more rapidly than did the farms operated by their owners. For example, the debt on the same owner farms decreased by 1.5 per cent of their 1925 value. Meanwhile the

tenant-operated farms in debt on both dates increased their debt ratios 1.2 per cent of their 1925 value and debt on manager farms

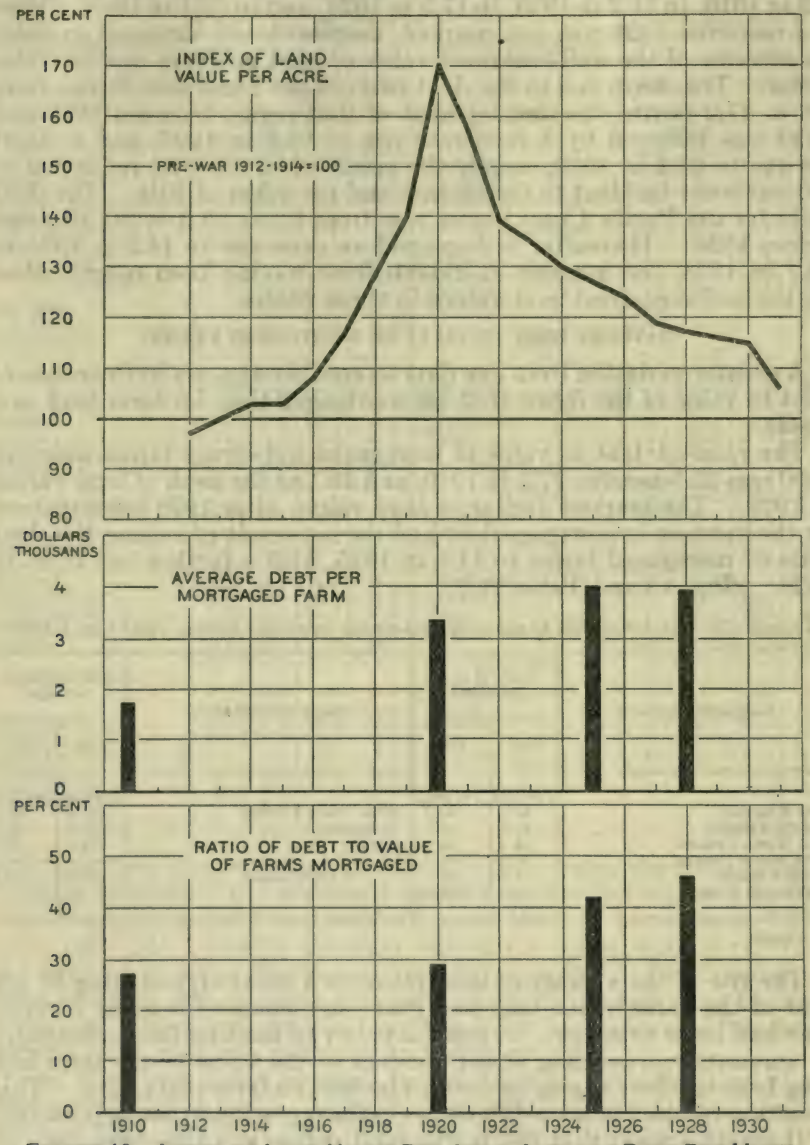

FIGURE 10.—INDEX OF LAND VALUE PER ACRE, AVERAGE DEBT PER MORTGAGED FARM, AND RATIO OF DEBT TO VALUE OF FARMS MORTGAGED

The index of land value per acre, with 1912–1914 as a base of 100, rose to 170 in 1920 and fell to 117 in 1928. The average indebtedness per farm during this period increased so that the ratio of debt to value of full-owner farms mortgaged rose from 27.3 in 1910 to 29.1 in 1920, to 41.9 in 1925, and to 46 in 1928. After 1920 the steady fall in land prices combined with continued increase in indebtedness in most States, resulted in a ratio of debt to value which approached the usual loaning limit of many important lending agencies.

reporting in this class increased 2.3 per cent of value. Of farms reporting debt in 1925 and 1928, full-owner farms had debt ratios averaging 41.6 in 1925, tenant farms had an average ratio of 37.5 per

cent, and manager farms had a ratio of 31.4. Thus tenant and manager farms, having had a lower debt in 1925, were able to obtain additional loans with less difficulty.

These comparisons indicate that the increase in the amount of mortgage credit during the period 1925 to 1928 was due more to the number of farms mortgaged than to the increase in debt per farm. Lenders accustomed to regard 50 per cent of value as the loan ratio limit might be expected to give more attention to the size of the owner's equity during a period when the land-value index was declining from 127 to 117. The net result of this situation was therefore a restrictive policy on loans representing high debt ratios.

The ratio of debt to value of tenant-operated farms in 1925 and 1928 appears to have been not greatly different from that on owner farms. In 1925 the debt ratio for tenant farms averaged 38.2 as compared with 41.9 for full owners, or about 10 per cent less. Lower ratios on tenant farms appeared in seven of the nine geographic divisions as well as for the country as a whole, while the South Atlantic and East South Central divisions had debt ratios on tenant farms of 38.4 and 44.2, respectively, the corresponding figures for owner farms being 37.1 and 41.9. (Table 23.)

TABLE 23.—*Ratio of debt to value of mortgaged farms, 1925, by tenure and States*

State and geographic division	Ratio of debt to value on mortgaged farms		State and geographic division	Ratio of debt to value on mortgaged farms	
	Owner-operated farms	Tenant-operated farms		Owner-operated farms	Tenant operated farms
	Per cent	*Per cent*		*Per cent*	*Per cent*
Maine	41.3	32.3	South Carolina	40.6	42.0
New Hampshire	39.5	30.9	Georgia	41.8	43.3
Vermont	46.4	36.3	Florida	25.8	26.7
Massachusetts	37.2	29.1			
Rhode Island	38.0	29.8	South Atlantic	37.1	38.4
Connecticut	37.6	29.4			
			Kentucky	43.3	45.7
New England	40.1	31.4	Tennessee	41.0	43.2
			Alabama	41.9	44.2
New York	41.6	35.6	Mississippi	41.2	43.5
New Jersey	38.9	33.3			
Pennsylvania	41.1	35.2	East South Central	41.9	44.2
Middle Atlantic	41.1	35.2	Arkansas	40.1	36.5
			Louisiana	42.9	39.0
Ohio	43.8	38.4	Oklahoma	39.7	36.1
Indiana	39.8	38.5	Texas	35.8	32.1
Illinois	40.8	42.0			
Michigan	42.5	41.1	West South Central	37.4	34.0
Wisconsin	49.0	43.0			
			Montana	44.7	38.7
East North Central	44.2	37.5	Idaho	45.0	39.0
			Wyoming	44.2	38.3
Minnesota	43.6	51.6	Colorado	42.6	36.9
Iowa	49.2	45.2	New Mexico	37.1	32.1
Missouri	44.6	56.4	Arizona	36.7	31.8
North Dakota	41.1	46.1	Utah	44.2	38.3
South Dakota	42.7	33.1	Nevada	45.2	39.1
Nebraska	42.2	50.8			
Kansas	39.0	33.0	Mountain	43.2	37.4
West North Central	44.9	43.6	Washington	37.2	24.9
			Oregon	37.7	25.3
Delaware	43.8	45.3	California	33.8	22.7
Maryland	42.4	43.9			
District of Columbia	34.7	35.9	Pacific	34.9	23.4
Virginia	35.1	36.3			
West Virginia	35.9	37.2	United States	41.9	38.2
North Carolina	36.4	37.7			

The debt status of tenant farms owned by active farmers is less favorable than for other tenant farms or for farms operated by their owners. This is indicated by debt frequency and by debt ratios. The Census of 1925 reported full-owner farms mortgaged in 34 per cent of the cases, as compared with 32.5 per cent for all tenant-operated farms when computed on a comparable basis. (Table 17.) Reports in this study showed that tenant farms owned by active farmers were mortgaged in 45.9 per cent of the cases, while other tenant farms had only 35.9 per cent mortgaged. (Table 18.) Full-owner farms reported in the census of 1925 had average debt ratios of 41.9, farmer-owned tenant farms reporting in this study averaged 45.3, and the debt ratio on other tenant farms was 32.9. (Tables 23 and 24.) This may indicate in part a greater disposition of active farmers to go into debt for additional land, and in part lower receipts from rented farms than from owner operated farms.

TABLE 24.—*Ratio of debt to value of tenant-operated farms, by type of ownership, 1925 and 1928*

Geographic division	Owned by active farmers		Owned by nonfarmers		Geographic division	Owned by active farmers		Owned by nonfarmers	
	1925	1928	1925	1928		1925	1928	1925	1928
	Per cent	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*
New England	43.3	55.7	26.3	31.5	West South Central	35.3	28.0	33.3	35.0
Middle Atlantic	36.3	32.7	35.6	37.0	Mountain	32.7	28.9	38.1	35.9
East North Central	35.3	34.5	36.8	36.1	Pacific	55.9	49.2	7.8	22.1
West North Central	50.6	49.0	41.5	39.7					
South Atlantic	37.1	37.4	33.2	37.1	United States	45.3	41.6	32.9	35.2
East South Central	43.9	38.7	39.4	38.1					

The generally heavier debt on tenant farms owned by active farmers is evident from 1928 data as well as from 1925 reports. Of a total of more than 5,700 tenant and manager farms reporting in 1928, tenant farms owned by active farmers had mortgages in 1925 in 41.6 per cent of all cases, whereas in 1928, 45.9 per cent were mortgaged. Other tenant farms which reported 35.6 per cent mortgaged in 1925 had about the same per cent, 35.9, in 1928. This greater frequency of debt occurred in all sections but was most strikingly illustrated in the East North Central and West North Central States where farmer-owned tenant farms were mortgaged in 60.4 and 56.3 per cent of all cases reporting, while other tenant farms had a debt frequency of only 36.6 and 43.7 per cent, respectively. (Table 18.)

The net result of this greater frequency and higher ratio of debt to value of farmer-owned land rented to others indicates that of all farms rented to others by the farmer approximately one-quarter of the value is covered by debt, and that other tenant farms carry mortgages equal to only one-sixth of the farm value, that is 23.9 and 16.2 per cent, respectively. It may therefore be concluded also that active farmers owe approximately 75 per cent of all farm-mortgage debt and that other owners owe about 25 per cent of the total.

FREQUENCY DISTRIBUTION OF RATIOS OF DEBT TO VALUE OF MORTGAGED FARMS IN 1925 AND 1928

During the time that the average ratio of debt to value of mortgaged farms was rising above 40 per cent, many mortgages constituted higher proportions of the value of the farms. Large numbers of loans made during the war period or in the years following came to represent high percentages of the existing values of the farms. Many of these were subsequently renewed to include delinquent interest or other debt; in other cases, second mortgages given as security to other lenders contributed to the increasing group of farms with indebtedness equal to the greater part of the value of the farm. (Fig. 11.)

A classification of mortgaged farms according to their ratios of debt to value indicates that a considerable part of all such farms had a high percentage of debt in 1925 and 1928. (Table 25.) Figure 11 illustrates the wide range that such ratios have among the mortgaged farms for each geographic division and in the United States as a whole. A generally larger percentage of farms with high ratios appeared for 1928 than for 1925, mainly because of continued decline in land value in all divisions save New England and increased indebtedness on farms in most of the other divisions. By reason of closer proximity of the reporting date, approximately six months from the time to which the report referred, the report for 1928 was more nearly a fair cross-sectional representation of farm-mortgage-debt ratios than was the distribution shown for 1925.[11]

[11] The debt on each farm reporting mortgage in 1925 or 1928 was first converted to a percentage of the value of the mortgaged land in the corresponding year. The resulting ratios were then grouped into 21 classes, 20 representing class intervals of 5 per cent and 1 group composed of those farms with indebtedness over 100 per cent of the value of the farm. Separate ratios and distributions were made for each year, 1925 and 1928.

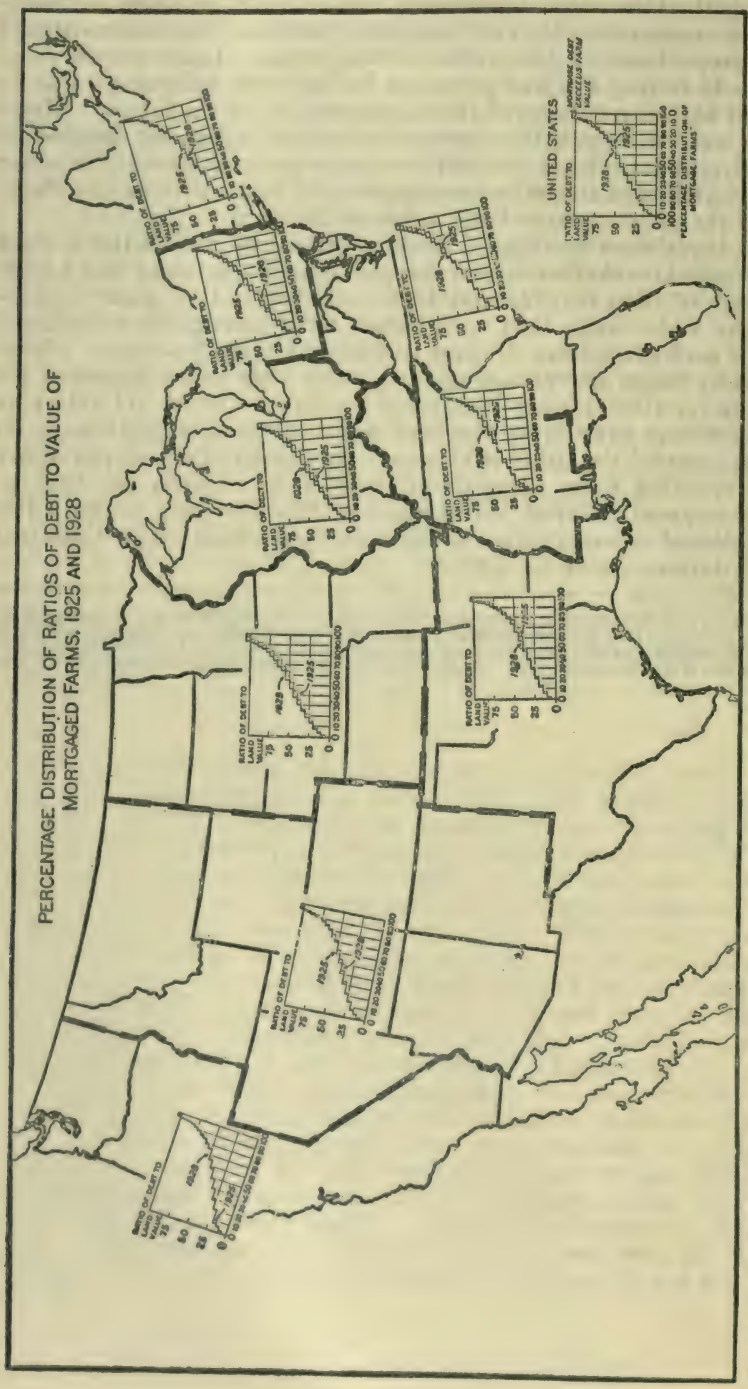

FIGURE 11.—In 1928 over 35 per cent of mortgaged farms had indebtedness amounting to more than half of the value of the land as declared by the owner. Over 12 per cent of the mortgaged farms had debt amounting to 75 per cent of the value of the land, and over 4 per cent of the farms had debt in excess of the full value of the land. The largest number of high ratios was found in the West North Central States, the lowest was in New England

TABLE 25.—*Percentage distribution of ratios of debt to value of farms reporting mortgage debt, January 1, 1925 and 1928,*[1] *by geographic divisions*

Geographic division	1928 ratio groups: Percentage of 1928 debt to 1928 value of farms mortgaged																			
	0 to 5	6 to 10	11 to 15	16 to 20	21 to 25	26 to 30	31 to 35	36 to 40	41 to 45	46 to 50	51 to 55	56 to 60	61 to 65	66 to 70	71 to 75	76 to 80	81 to 85	86 to 90	91 to 95	96 to 100	Over 100
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
New England	3.0	7.0	9.2	11.1	7.2	9.3	9.7	10.4	4.7	7.0	3.2	5.4	2.4	3.8	1.5	1.4	0.7	0.6	0.4	0.7	1.3
Middle Atlantic	1.7	4.3	7.9	6.6	7.4	7.4	7.8	9.7	7.5	8.8	5.8	4.5	4.4	3.4	3.0	2.9	2.1	.9	.7	.6	2.6
East North Central	1.3	3.2	4.4	5.4	6.3	6.8	6.3	6.8	7.2	7.2	8.2	6.3	4.4	5.2	3.2	3.5	3.0	2.4	1.4	1.3	6.2
West North Central	1.2	2.2	3.9	5.7	6.0	5.5	5.9	8.4	8.3	8.1	9.2	4.4	5.2	4.6	4.0	3.2	2.3	2.2	1.3	1.1	7.3
South Atlantic	1.8	5.2	5.6	9.0	8.6	7.2	7.3	6.8	5.9	5.5	9.2	3.0	5.6	3.5	2.4	2.1	1.9	1.7	.9	.9	5.9
East South Central	2.4	3.7	2.6	7.3	8.2	7.4	7.9	8.6	8.6	7.9	10.3	5.5	5.1	2.1	3.5	1.1	1.4	1.2	.6	.3	4.3
West South Central	1.4	5.7	6.3	8.3	8.7	8.7	9.0	10.1	7.9	7.8	6.0	3.2	4.2	2.5	2.1	1.6	1.7	.7	.6	.2	3.3
Mountain	1.0	3.9	3.6	6.6	7.5	10.6	9.9	11.0	8.6	8.7	5.7	3.7	3.9	3.1	2.4	2.0	1.5	1.2	.9	.2	4.0
Pacific	1.9	2.2	3.8	12.9	9.5	9.8	9.4	8.6	8.3	9.0	4.8	4.0	3.0	2.5	2.4	1.8	1.3	.9	.4	.2	3.3
United States	1.7	3.9	5.2	7.1	7.4	7.4	7.9	8.4	8.2	7.1	8.5	3.5	5.2	3.1	3.2	2.4	2.1	1.3	1.0	1.0	4.4

Geographic division	1925 ratio groups: Percentage of 1925 debt to 1925 value of farms mortgaged																			
	0 to 5	6 to 10	11 to 15	16 to 20	21 to 25	26 to 30	31 to 35	36 to 40	41 to 45	46 to 50	51 to 55	56 to 60	61 to 65	66 to 70	71 to 75	76 to 80	81 to 85	86 to 90	91 to 95	96 to 100	Over 100
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
New England	2.2	5.8	8.4	12.5	6.8	9.7	7.5	10.9	6.8	6.6	3.7	5.1	2.9	3.3	2.5	2.5	0.5	0.4	0.4	0.8	0.7
Middle Atlantic	1.3	2.8	5.1	5.7	9.9	6.6	6.6	10.8	5.8	11.4	3.4	6.6	4.7	4.5	2.9	3.7	2.4	2.2	.9	1.8	.9
East North Central	1.1	3.7	5.6	6.3	6.9	7.7	7.2	7.7	8.8	10.2	4.1	6.0	3.3	4.8	4.1	2.8	1.0	1.7	1.3	2.0	3.7
West North Central	1.6	3.0	4.4	5.7	6.6	5.2	9.2	8.5	8.6	11.0	4.5	6.3	5.1	3.9	3.3	2.8	2.3	1.1	1.1	3.3	2.5
South Atlantic	1.6	6.0	6.5	7.8	7.5	7.0	8.1	8.7	4.8	10.8	3.6	6.8	3.0	4.2	2.6	2.2	1.6	1.7	.9	2.6	2.0
East South Central	1.2	1.5	2.5	10.2	6.8	5.9	11.8	11.5	8.1	11.1	2.8	7.1	2.2	3.4	3.4	1.9	2.2	1.5	.3	.9	3.7
West South Central	1.5	3.9	6.5	9.0	8.9	10.0	9.0	12.5	6.2	10.7	2.3	4.5	3.2	2.9	2.9	2.4	.6	.6	.3	1.8	.3
Mountain	.5	2.7	4.5	6.9	7.5	8.7	9.8	10.6	7.8	11.8	3.8	6.5	3.4	3.8	2.0	1.9	1.2	.7	.3	2.3	3.3
Pacific	1.2	4.4	6.1	8.4	9.0	10.6	9.3	9.5	7.6	10.6	2.7	4.6	2.0	3.8	2.3	2.2	2.9	.7	.7	2.2	1.2
United States	1.3	3.8	5.6	7.5	7.7	7.8	8.5	9.6	7.4	10.5	3.6	5.9	3.5	4.0	3.0	2.6	1.4	1.2	.8	2.2	2.1

[1] Based on reports of 22,352 farms reporting in 1928.

The range of debt ratios in 1925 for the country as a whole showed that approximately 30 per cent of the mortgaged farms reporting in 1928 had indebtedness of more than one-half of the value of the farms mortgaged, more than 10 per cent with mortgages above three-fourths of the value of the farm, while 2.1 per cent had debts greater than the total value of the farms. Farms on which the mortgages were foreclosed or which changed hands otherwise because of pressure of debt during the three years 1925 to 1928 are not included in this distribution. This absence of the full number of heavily indebted farms is suggested by the fact that the average ratio of debt to value of the reporting farms was less than that reported by the census on all owner farms as of the same date.

Despite the exclusion of many cases of high debt ratios, all the geographic divisions showed a considerable proportion of farms with debts ranging up toward the full value of the farm or above, though the proportion of high ratios varied considerably from one division to another. New England had the smallest percentage of high debt ratios, only 23 per cent being above half the value of the farm, and 5 per cent above three-fourths of the value. The West North Central had 36 per cent of its mortgaged farms with debt in excess of half the value of the land, 13 per cent above three-fourths, and 2.5 per cent above full value. (Table 26.)

TABLE 26.—*Cumulative percentages of mortgaged farms having ratios of debt to value over 50 per cent*

JANUARY 1, 1928

Geographic division	Over 100 per cent	Over 95 per cent	Over 90 per cent	Over 85 per cent	Over 80 per cent	Over 75 per cent	Over 70 per cent	Over 65 per cent	Over 60 per cent	Over 55 per cent	Over 50 per cent
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
New England	1.3	2.0	2.4	3.0	3.7	5.1	6.6	10.4	12.8	18.2	21.4
Middle Atlantic	2.6	3.2	3.9	4.8	6.9	9.8	12.8	16.2	20.6	25.1	30.9
East North Central	6.2	7.5	8.9	11.3	14.3	17.8	21.0	26.2	30.6	36.9	45.1
West North Central	7.3	8.4	9.7	11.9	14.2	17.4	21.4	26.0	31.2	35.6	44.8
South Atlantic	5.9	6.8	7.7	9.4	11.3	13.4	15.8	19.3	24.9	27.9	37.1
East South Central	4.3	4.6	5.2	6.4	7.8	8.9	12.4	14.5	19.6	25.1	35.4
West South Central	3.3	3.5	4.1	4.8	6.5	8.1	10.2	12.7	16.9	20.1	26.1
Mountain	4.0	4.2	5.1	6.3	7.8	9.8	12.2	15.3	19.2	22.9	28.6
Pacific	3.3	3.5	3.9	4.8	6.1	7.9	10.3	12.8	15.8	19.8	24.6
United States	4.4	5.4	6.4	7.7	9.8	12.2	15.4	18.5	23.7	27.2	35.7

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New England	0.7	1.5	1.9	2.3	2.8	5.3	7.8	11.1	14.0	19.1	22.8
Middle Atlantic	.9	2.7	3.6	5.8	8.2	11.9	14.8	19.3	24.0	30.6	34.0
East North Central	3.7	5.7	7.0	8.7	9.7	12.5	16.6	21.4	24.7	30.7	34.8
West North Central	2.5	5.8	6.9	8.0	10.3	13.1	16.4	20.3	25.4	31.7	36.2
South Atlantic	2.0	4.6	5.5	7.2	8.8	11.0	13.6	17.8	20.8	27.6	31.2
East South Central	3.7	4.6	4.9	6.4	8.6	10.5	13.9	17.3	19.5	26.6	29.4
West South Central	.3	2.1	2.4	3.0	3.6	6.0	8.9	11.8	15.0	19.5	21.8
Mountain	3.3	5.6	5.9	6.6	7.8	9.7	11.7	15.5	18.9	25.4	29.2
Pacific	1.2	3.4	4.1	4.8	7.7	9.9	12.2	16.0	18.0	22.6	25.5
United States	2.1	4.3	5.1	6.3	7.7	10.3	13.3	17.3	20.8	26.7	30.3

Mortgaged farms for 1928 showed a definitely larger number with high debt ratios than for 1925 notwithstanding the factors tending to produce opposite results. The lower land values and greater debt of this period left many farms with impending foreclosure. In New

England alone the spread of ratios of debt to value was similar to that of 1925. (Table 25.)

The North Central divisions again showed much the heaviest indebtedness with reference to the values of the farms mortgaged, as well as in absolute amount. Forty-five per cent of the mortgaged farms of the West North Central States had ratios over half the farm value, 17 per cent had debts over three-fourths of the value, and 7.3 per cent carried mortgages greater than the value as declared by the owner of the farm. The East North Central States showed a similar distribution.

The Middle Atlantic States were in better condition with 31 per cent above one-half the value, 10 per cent above three-fourths of the value, and 2.6 per cent above full value of the farms mortgaged. The Mountain States in 1928 had only 29 per cent of the mortgaged farms with debt over half the value of the farms mortgaged, 10 per cent over three-fourths, and 4 per cent above full value of the farms.

The East South Central States in 1928 reported 35 per cent of their mortgaged farms with debt ratios over one-half of the farm value, and the West South Central States had only 26 per cent of their mortgaged farms in that class. The Pacific division had fewer high debt ratios than any other save New England, having had 25 per cent of the mortgaged farms with debt over half the farm value, 8 per cent over three-fourths of the value, and 3 per cent above full value.

Distributions of mortgaged farms on the basis of the ratio of their indebtedness to their value present some similarity among the several geographic divisions both for 1928 and 1925. (Table 26.) In 1928 in all divisions save New England 25 to 45 per cent of the mortgaged farms had debts above half of the value, from 8 to 18 per cent had mortgages over 75 per cent of value, and from 3 to 7 per cent reported indebtedness equal to or in excess of the value of the farm.

If more farms had high debt ratios in 1928 than in 1925, it would appear that throughout this period a considerable number of farmers were at the edge of insolvency—defaulting on debt, abandoning their farms to creditors, or continuing for a time with indebtedness greater than the value of the land.

RELATION OF HIGH DEBT RATIOS TO FORECLOSURES

The existence of a considerable percentage of mortgages in amounts approaching the value of the security or actually in excess of the farm value commonly gives rise to problems for both borrowers and lenders. Inability to meet payments on interest, principal, or taxes may endanger the farmer's equity or the lender's principal or both. It is not surprising, therefore, that the number of farms with debt ratios near the full value of the property should show a significant correspondence to the number of farms undergoing foreclosure.

For this comparison the percentage of farms foreclosed on was divided by the percentage of full-owner farms reporting mortgage in the 1925 census. The result showed a general similarity between high-debt ratios and foreclosures in most divisions, and in some the figures are almost identical. In the country as a whole 4.9 per cent of all mortgaged farms were foreclosed in 1928, (*29, p. 44*) and 4.4 per cent of all farms were reported as having debt equal to, or greater than, the value of the farm. Unpaid interest and taxes on other farms might readily make the total number of farms with no equity equal the number of foreclosures. (Table 27.)

TABLE 27.—*Relation between high debt to value ratios and foreclosures*

Geographic division	Foreclosure as percentage of all farms 1928 [1]	Farms mortgaged as percentage of all farms, 1928	Foreclosure as percentage of all farms, mortgaged	Distribution of debt ratios above 50 per cent of land value as percentage of all farms mortgaged					
				Over 100 per cent	Over 90 per cent	Over 80 per cent	Over 70 per cent	Over 60 per cent	Over 50 per cent
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
United States	1.76	36.0	4.9	4.4	6.4	9.8	15.4	23.7	35.7
New England	.77	32.8	2.3	1.3	2.4	3.7	6.6	12.8	21.4
Middle Atlantic	.84	31.1	2.7	2.6	3.9	6.9	12.6	20.6	30.9
East North Central	1.65	38.3	4.3	6.2	8.9	14.3	21.0	30.6	45.1
West North Central	2.73	49.2	5.5	7.3	9.7	14.2	21.4	31.2	44.8
South Atlantic	1.64	26.0	6.3	5.9	7.7	11.3	14.4	24.9	37.1
East South Central	1.46	26.4	5.5	4.3	5.2	7.8	12.4	19.6	35.4
West South Central	1.44	38.7	3.7	3.3	4.1	6.5	10.2	16.9	26.1
Mountain	2.74	45.1	6.1	4.0	5.1	7.8	12.2	19.2	28.6
Pacific	1.57	45.0	3.5	3.3	3.9	6.1	10.3	15.8	24.6

[1] U. S. Dept. Agr. Circular 101 (*30, p. 45*).

Among geographic divisions foreclosures ranged from 2.3 per cent of the mortgaged farms in New England to 6.3 per cent in the South Atlantic division, as compared with farms having debts over 100 per cent of value ranging from 1.3 per cent in New England to 7.3 per cent in the West North Central division.

In most of the divisions the percentage of farms reporting debt equal to, or in excess of, value was less than the percentage of foreclosures. Higher interest rates, less regular income in some regions, and accumulated taxes in many others were other factors tending to bring about foreclosures before the debt had reached full value of the property. In the Mountain division, where the foreclosure rate in 1928 was approximately 6 per cent of all farms mortgaged as compared with 4 per cent of such farms having debt equal to value, the average foreclosure evidently occurred after the indebtedness reached an average of about 85 per cent of the value of the farm.

A similar comparison for the East South Central States indicates that in that area foreclosures occurred on the average where the principal of the mortgage reached about 90 per cent of the farm value. The higher rates of interest in these areas would hasten delinquency and the covering of equities. The fact that the Mountain States had already shown a shrinkage in mortgage debt between 1920 and 1925 suggests that the loans on lands in that division were more responsive to land-value changes, a result partly attributable to unsuccessful irrigation projects. Further decline would occur before foreclosure could be completed. Meanwhile cost of proceedings, accumulated interest and taxes, and frequently, deterioriation of the property, might readily consume any equity in the farm or even result in a loss.

In the North Central States, farms on which the mortgages were foreclosed were not so numerous as were the farms with debt over their full value. The East and West North Central divisions had, respectively, 6.2 and 7.3 per cent of mortgaged farms with debt above their value, whereas the foreclosures among mortgaged farms were only 4.3 and 5.5 per cent. This situation suggests that in areas in which the debtor has a reasonably good chance of caring for his debt, there has been a growing reluctance of creditors to take over mortgaged farms. To some extent this may be true of the country as a

whole. The number of foreclosures per year, however, was about equal during the period under consideration, being 17.4 and 17.6 per 1,000 farms in 1926 and 1928, respectively, while 1927 showed 18.2 per cent.

RATIO OF NEW MORTGAGE DEBT TO VALUE OF FARMS WITH SAME OWNERS

New mortgages incurred between 1925 and 1928 on farms not previously indebted represented relatively low proportions of the value. The average debt ratio for all farms of this class reporting was slightly less than 30 per cent, and the geographic divisions had ratios ranging from about 23 per cent for the South Central States to about 38 per cent in the North Atlantic. (Table 28.) Although some ratios were higher, these reports indicate that the average original mortgage obtained during recent years by the farmer who already owned his farm was less than a third of the value of the farm. The high debt ratios frequently found are thus seen to be the result of gradual additions to the original mortgages, a consequence of lowered values of farms mortgaged when prices were higher, or an accompaniment of land transfers.

TABLE 28.—*Comparison of average ratios of debt to value of transferred farms before and after transfer, and of farms not previously mortgaged*

[Average 1925–1928]

Geographic division	Average ratio of debt to value of transferred farms before transfer	Average ratio of debt to value of transferred farms after transfer	Average ratio of debt to value of new mortgages on farms not previously mortgaged	Geographic division	Average ratio of debt to value of transferred farms before transfer	Average ratio of debt to value of transferred farms after transfer	Average ratio of debt to value of new mortgages on farms not previously mortgaged
	Per cent	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*
New England	45.4	48.8	35.7	West South Central	57.1	59.7	23.2
Middle Atlantic	49.8	54.4	37.7	Mountain	60.6	59.0	28.5
East North Central	60.5	73.0	29.7	Pacific	54.2	57.4	28.5
West North Central	67.3	70.0	34.0				
South Atlantic	62.2	71.7	32.4	United States [1]	59.2	65.0	29.6
East South Central	53.7	58.9	22.7				

[1] Weighted by all farms.

HEAVY INDEBTEDNESS ON TRANSFERRED FARMS

By contrast, farms that were transferred to new owners during the period 1925 to 1928 carried indebtedness averaging about two-thirds of the value of the property. An average of all reports covering this class of farms showed that the ratio of debt to value was over 59 per cent before transfer and 65 per cent afterwards. (Table 28.) Even allowing for the indebtedness involved in forced sales, this suggests that the presence of debt on a farm may be an incentive for owners to dispose of land and for prospective buyers to purchase. Purchasers of land rather commonly have available only a part of the consideration, whether in periods of high or low prices. A farm already mortgaged, therefore, represents a smaller equity involved for both buyer and seller and may be a convenient basis of trade.

RELATION OF FIXED DEBT TO LAND INCOME

Although only 36 per cent of farms were reported by the census as mortgaged in 1925 and the total fixed debt on farms in 1925 constituted but 18.9 per cent of the value of all land and buildings, the consequence to the income of agriculture is more than that indicated by this proportion. The average rate paid on this debt in 1928 was nearly 6 per cent, whereas net cash rents in six North Central States, the area having two-thirds of all mortgage debt, were only 3.5 [12] per cent of the farm value and the average rate earned on operators' net capital investment in the United States from 1923 to 1929 was 3.2 per cent (*17*). If other areas yielded net returns equal to the rate of return of this principal agricultural region, it would appear that the cost of carrying each hundred dollars of debt consumed the income of more than $170 of farm value. In other words, approximately one-third of the net return from all farm land and buildings in the United States in 1925 was required to meet the fixed obligations represented by the mortgage debt on farms.

METHOD OF COMPUTING RATIO OF DEBT TO VALUE OF FARMS

The ratio of debt to value of full-owner farms for 1925 was obtained for each State directly from the census of that year. To obtain corresponding ratios for 1928, the 1925 debt frequency or percentage of full-owner farms mortgaged was first divided into the 1928 frequency to obtain a correction factor. This correction factor was divided into the number of full-owner farms mortgaged in 1925 to compute the number mortgaged in 1928. This computed number of farms mortgaged was in turn divided into the estimated total mortgage debt of full-owner farms in 1928 to obtain a computed average debt per mortgaged farm in 1928. The average value per mortgaged farm in 1928, computed by applying to the average value of such farms in 1925 the land-value index relative 1928/1925, was then divided into the average debt per farm to obtain the average ratio of debt to value in 1928 on full-owner farms of the same ownership in 1925 and 1928. To this ratio was added or subtracted the fraction of increase or decrease in ratio of debt to value on account of farms transferred between 1925 and 1928, obtained as follows: The percentage of all farms transferred during the 3-year period as reported by bankers and recorders was multiplied by the percentage of such transferred farms which were mortgaged to obtain the percentage which transferred mortgaged farms were of all farms. This latter figure was divided by the percentage of all farms with mortgage in 1928 and the result multiplied by the percentage increase or decrease in ratio of debt to value on mortgaged farms transferred. This difference, expressed in terms of 1925 land values amounting to 0.7 for the country, was divided by the 1928/1925 land value-index relative to obtain its expression in terms of 1928 values.

The ratio of debt to value of mortgaged full-owner farms as reported in the 1925 census was divided by the corresponding ratio derived from the sample for the same year to obtain a correction factor to be used for tenures other than owners for 1925 and 1928.

The ratio of debt to value of mortgaged tenant-operated farms in 1925 as shown by the used groupings was corrected by the factor obtained above to get a final figure for 1925 for geographic divisions

[12] This figure is the result of applying the ratio of net to gross rent ratios in Iowa to a simple average of the gross rent ratios of Missouri, Minnesota, Illinois, Indiana, Ohio, and Iowa (*29, pp. 27, 29*).

and for the separate States in the East and West North Central divisions. All other State figures were obtained by the proportion

$$\frac{a}{b}=\frac{a^1}{x}$$

in which

a = the 1925 census division ratio for owners,
b = 1925 State ratio for owners,
a^1 = corrected division ratio for tenants,
x = computed State ratio for tenants.

The 1928 data covering ratio of debt to value of tenant farms were first treated by the same process as for 1925. To the resulting figures were added or subtracted the percentages of increase or decrease in ratio of debt to value due to transfer as in the case of owner-operated farms.

A slight error occurs in this and other computations because of an inability to allow for differences in sample data for 1925 but reported in 1928, which may be caused by foreclosures and other changes tending to make reports unrepresentative of 1925 conditions. To overcome this difficulty, separate data would be required showing the debt position of foreclosed mortgaged farms.

INTEREST RATES AND THEIR RELATION TO FARM-MORTGAGE FINANCING

INTEREST RATES ON LOANS OUTSTANDING IN 1928

The weighted average interest rate reported by farmers on farm mortgage loans outstanding January 1, 1928, was 5.8 per cent, which compares with 6.1 per cent shown by the census of 1920, and 7.1 per cent by that of 1890. (Table 29.) The rate of 5.8 per cent for 1928 probably is lower than the actual average for all farms. Farmers replying to special inquiries generally represent farms above average size and value and therefore more advantageous financing arrangements. No such possible difference will occur in the loans by the Federal land banks, however, since these institutions have uniform rates for all loans made at a given time. Other interest rates reported here, though perhaps slightly lower than complete data would show, are probably representative of relative differences between various sources and divisions.

TABLE 29.—*Interest charged by principal lending agencies on farm mortgage loans outstanding, January 1, 1928, by geographic divisions* [1]

Geographic divisions	Principal lending agency									All sources [2]	Average rate of all owner-operated farms, 1920 [3]
	Federal land banks	Joint-stock land banks	Commercial banks	Mortgage companies	Insurance companies	Retired farmers	Active farmers	Other individuals	Other agencies		
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
New England	5.4	6.0	5.9	------	6.0	5.8	5.7	6.0	5.8	5.8	5.7
Middle Atlantic	5.5	6.0	6.0	5.2	6.2	5.5	5.5	5.6	5.8	5.7	5.4
East North Central	5.5	5.9	6.1	5.6	5.3	5.4	5.8	5.6	6.2	5.6	5.6
West North Central	5.4	5.8	6.2	5.7	5.3	5.4	5.8	5.6	5.7	5.5	5.8
South Atlantic	5.6	5.9	7.2	6.3	6.7	6.7	7.1	7.0	6.8	6.6	6.4
East South Central	5.6	5.9	6.6	6.2	5.7	7.0	5.9	6.5	6.2	5.9	6.4
West South Central	5.4	6.0	7.7	6.9	6.7	7.0	7.7	7.9	5.7	6.6	7.2
Mountain	5.6	6.0	7.6	7.3	6.8	6.7	7.5	7.4	7.1	6.7	7.3
Pacific	5.6	6.0	6.9	6.4	6.1	6.4	6.4	6.5	6.6	6.5	6.6
United States	5.5	5.9	6.7	6.1	5.5	5.8	6.1	6.2	6.2	5.8	6.1

[1] Reports from farmers. [2] Weighted by geographic divisions. [3] Census, 1920 (*19*).

Both the general trend toward lower interest rates of all kinds and the progress of improved farm-mortgage financing have been forces working toward lower costs of farm real estate loans by 1928. It is therefore probable that some decline has occurred since 1920. Since the rates represent outstanding loans, they reflect differences prevailing in the several geographic divisions at the time the loans were made rather than the current rate in 1928.

Among geographic divisions the West North Central States had the lowest rate, 5.5 per cent, and the East North Central group was next with 5.6 per cent. The highest average rate, 6.7 per cent, was reported from the Mountain division, and the West South Central and South Atlantic States each reported 6.6 per cent.

INTEREST RATES OF VARIOUS LENDING AGENCIES

Among the various sources of loans the lowest average rates for the country as a whole were reported on loans by the Federal land banks and insurance companies, each being 5.5 per cent. Joint-stock land banks were next lowest of the institutional lenders with 5.9 per cent, the mortgage companies' rates averaged 6.1 per cent, and the commercial banks averaged 6.7 per cent. Rates on loans from individuals held to rates of 6.1 and 6.2 per cent, and loans from retired farmers carried rates of 5.8 per cent. These rates for principal lenders, though generally comparable, are not entirely so because of different distributions of lenders' loans among areas of unequal credit cost and risk. (Table 10.) For example, mortgage companies have a concentration of loans in Southern States where rates usually are higher than the national average; insurance companies have most of their loans in the North Central area; and commercial banks are important in the East.

The various agencies showed a tendency to maintain their relative rate positions throughout the several geographic divisions, with some important exceptions. Of the nine sources the Federal and joint stock land-banks showed the least variation from their national average, a natural consequence of their legal limitations of 6 per cent for rates charged and the confinement of loans to first mortgages. Insurance loans on the other hand ranged from 5.3 per cent in the North Central to 6.8 per cent in the Mountain States. Mortgage companies' loan rates averaged only 5.2 per cent in the Middle Atlantic States, and 5.7 per cent in the West North Central, but were 7.3 per cent in the Mountain division. Commercial banks were highest in rates of all lending institutions in nearly all divisions, ranging from 5.9 per cent in New England to an average of 7.7 per cent in the West South Central States. Rates on loans from individuals showed a general correspondence to the rates of commercial banks in the same areas.

DISTRIBUTION OF FARM-MORTGAGE DEBT BY RATE OF INTEREST

Approximately 30 per cent of all loans reported in 1928 had been made at an interest rate of 6 per cent; 28, at 5 per cent; 18, at 5.5 per cent; 9, at 7 per cent; and 6, at 8 per cent. (Table 30.) Six per cent was also the most frequent rate given in seven of the nine geographic divisions. In the West North Central division, however, the most frequent rate given was 5 per cent, and in the West South Central States 7 per cent was most common, although the loans at 6 and 8 per cent were nearly as numerous. A wide distribution of rates appeared

in the Mountain States, where 27 per cent of the loans carried 6 per cent, and the rates of 5.5, 7, and 8 per cent were represented by the respective percentages of 20, 16, and 20. Likewise in the Pacific States approximately 35 per cent of all loans were reported made at 6 per cent, and the same percentage at 7 per cent.

TABLE 30.—*Percentage distribution of mortgage debt on reporting farms, by rate of interest, for geographic divisions and the United States in 1928, compared with debt on full-owner farms, in 1920*

Geographic division	Mortgage loans reported		Distribution of debt according to interest rate						
	Number	Amount	Less than 4 per cent	4 per cent	Between 4 and 5 per cent	5 per cent	Between 5 and 5½ per cent	5½ per cent	Between 5½ and 6 per cent
All reporting farms:		*1,000 dolls.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
New England	668	1,123	0.05	0.91	0.41	15.46	0.32	11.78	-------
Middle Atlantic	802	1,935	.31	1.47	.20	21.25	1.82	15.58	-------
East North Central	1,242	7,009	-------	.68	-------	32.87	3.32	19.77	0.81
West North Central	1,875	15,123	-------	.27	.11	42.26	4.44	20.64	.47
South Atlantic	665	2,699	-------	.44	-------	1.57	.63	13.70	.13
East South Central	321	1,211	-------	-------	.13	10.29	2.25	32.90	1.57
West South Central	658	2,642	.03	.05	-------	15.87	.29	9.26	.10
Mountain	826	3,600	-------	-------	-------	5.43	.75	19.88	.21
Pacific	1,170	7,393	-------	.28	-------	2.11	.97	11.17	.22
United States	8,227	42,735	.02	.36	.07	28.37	2.92	18.46	.47
Census 1920—full-owner farms, United States	-------	-------	.34	1.86	1.16	19.07	.90	12.29	.94

Geographic division	Distribution of debt according to interest rate									
	6 per cent	Between 6 and 6½ per cent	6½ per cent	Between 6½ and 7 per cent	7 per cent	Between 7 and 8 per cent	8 per cent	Between 8 and 10 per cent	10 per cent	More than 10 per cent
All reporting farms:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
New England	64.27	-------	1.35	-------	3.94	0.06	1.15	-------	-------	0.30
Middle Atlantic	58.41	-------	-------	-------	.68	-------	.21	-------	0.07	-------
East North Central	33.31	0.24	2.15	-------	6.41	.05	.35	0.02	.01	.01
West North Central	22.96	.02	2.30	0.03	3.69	.39	2.04	.24	.14	-------
South Atlantic	46.46	-------	.45	-------	10.17	-------	21.25	-------	5.20	-------
East South Central	41.47	-------	.87	-------	1.20	-------	8.65	.05	.59	-------
West South Central	22.54	-------	2.03	.19	24.30	2.66	20.62	.49	1.56	.01
Mountain	26.95	-------	1.98	-------	16.40	1.70	19.62	2.12	4.96	-------
Pacific	35.11	.07	8.44	-------	34.86	1.56	5.00	.11	.10	-------
United States	30.06	.06	2.42	.03	9.28	.63	5.78	.28	.77	.02
Census 1920—full-owner farms, United States	39.13	.39	2.75	.25	9.24	.89	8.51	.73	1.50	.05

A comparison of the distributions of rates on loans reported in 1928 with those given in the 1920 census provides further evidence of a shift to lower levels. Loans at 6 per cent were dominant at both dates, but the percentage of the total at that rate had declined from 39 to 30 per cent. Loans reported above 7 per cent were less in amount than in 1920, and loans at 7 per cent were practically unchanged. The proportion of loans reported in 1928 at 5.5 per cent was 18 per cent as compared with 12, and loans at 5 per cent made

up 28 per cent of the total, as compared with 19 per cent on the earlier date. Even allowing for possible bias due to a disproportionate amount of better-than-average loans reported for 1928, it would appear that rates on farm mortgages outstanding in 1928 were more favorable to the borrower than in 1920.

Aside from the rate of 5.5 per cent, which accounted for 18 per cent of the total loans reported, rates of fractional amounts are relatively infrequent, 75 per cent of all mortgages being reported as bearing interest rates of even percentages.

This infrequency of mortgage-interest rates of other than full or half per cent quotations has practical significance for the farmer in selecting favorable times at which to obtain a mortgage. For example, this fact tells him that small changes in short-time money-market rates are not likely to be reflected in the mortgage rate. In most cases such changes are temporary. Since a rise in bond yields equal to 0.5 per cent usually continues for a period of six months or longer before it is reflected in farm-mortgage rates, the farmer may safely assume that new rates quoted to borrowers will not follow a rise in short-time rates in a short period of time, and that unless the short-term rates continue to rise, or if they soon decline, quoted mortgage rates may not change their original position. After quoted mortgage rates have once risen, however, the downward changes may be expected to occur only after a similar time lag.

ADDITIONAL CREDIT COST IN LAND PRICES

Even when the rates of interest and commission on the mortgage are high, these charges may not represent the full cost of the credit used if the mortgage has been given or assumed in part or full payment for the land. The price of land bought with the aid of mortgages representing a high or full percentage of the value of the land may require special caution because of the higher price incident to the liberal credit features.

In cases in which the selling price is higher than the price at which the land would sell for cash, the additional cost should be distributed over the term of the loan and added to the interest and commission in determining the total charge for the credit obtained. As in the case of merchant and dealer credit where this system has its fullest consequences, the cost of such credit may be considerably above the current rate of interest. Although a part of the charge may represent loss in handling the credit account, the purchaser who meets his obligation incurs the full expense. If the total credit-cost rate is greater than the rate of income, such purchase-money mortgages may be the first step toward later difficulty.

RELATION OF MONEY RATES TO FARM-MORTGAGE FINANCING SINCE 1917: THE LAG IN MORTGAGE RATES

The course of money rates since 1917, the first year of operation under the Federal farm loan act, has been characterized by four significant rises at intervals of three to six years, 1917, 1919 to 1920, 1922 to 1923, 1928 to 1930. A comparison of the relation of mortgage rates with short-term rates and bond yields during this time shows that mortgage rates on new loans from leading agencies lagged behind changes in rates on short-term loans and bond yields.

In 1920 to 1921 and again in 1928 to 1930 the rates quoted by the Federal land banks lagged approximately a year behind the changes in short-term rates and bond yields (7). (Fig. 12). The rates quoted to farmers began to rise about 12 months after the rise of bond yields and continued to rise for a somewhat shorter period than did the yield on bonds. The legal limit of 6 per cent on loans by the land banks prevents the rates of those institutions from going above that point, whereas the quotations of insurance companies and other private lending agencies follow the market. Hence in 1921 when the rate quoted by the Federal land banks had reached its legal limit of 6 per cent, insurance companies were loaning at about 6.5 per cent.

Likewise on the decline, quoted rates have continued high after bond yields have descended to lower levels. In 1922 the quoted rates of the Federal land banks were not lowered until nearly two years after the yield of their bonds had declined. This exceptionally long delay was due to the fact that because the Federal farm loan act forbids loans at rates higher than 6 per cent, the quoted rates from that source could not rise as high as market conditions would have required. Consequently, some time was required for the market rate to decline to the level of 6 per cent, from which point the decline could begin to be reflected in the rates quoted by the land banks. The loaning rate of insurance companies, as shown in Figure 12, indicates the trend of the unrestricted market. (*5, 1922, p. 159.*) The average quoted rate of 6.46 per cent on loans from that source for 1921 declined 0.5 per cent to an average of 6 per cent for loans made in 1922, the point from which land-bank quotations were lowered, and to less than 5.5 per cent in 1923, thus paralleling the decline in rates quoted by the land banks.

The usual lag of long-term interest rates behind short-term rate changes was again shown following 1928. Although short-term interest rates began to rise early in 1928, rates on farm mortgages continued favorable for a year afterward. The Federal land banks did not begin to raise their quotations until the fore part of 1929, and the increase in rates quoted by most insurance companies did not occur until July of that year. The 6 per cent loan-rate limit of the Federal land banks again effectively narrowed the range within which the loaning operations of those institutions were practicable.

Referring to this difficulty the Secretary of the Treasury (*12, p. 64*) stated the situation as follows:

> General conditions in the money market that affected the sale of all classes of securities, including obligations of the Government, naturally had their influence on farm loan bonds. The Federal land banks were faced with the choice of undertaking to issue long-term bonds in volume at high rates of interest in a situation that appeared to be temporary, or endeavoring to take care of their requirements by the issuance of bonds in minimum amounts supplemented by the utilization of repayments and installment payments on loans, and such temporary financing as seemed to be desirable and necessary. The banks chose the latter course, which appeared to be the wiser until the bond situation clears and improves. Federal land banks in the first part of the fiscal year issued bonds at 4¼ per cent and in the latter half at 4½ per cent. Banks issuing 4½ per cent bonds increased their lending rate from 5 or 5¼ per cent to 5½ per cent.
>
> Somewhat similar conditions confronted joint-stock land banks, which for the most part have been marking time, as far as undertaking to sell bonds is concerned, until they are able to dispose of their securities at satisfactory rates. Some joint-stock land banks issued bonds during the year at 4½ and 5 per cent and the lending rate in these cases was 5½ or 6 per cent, according to the rate borne by the bonds.

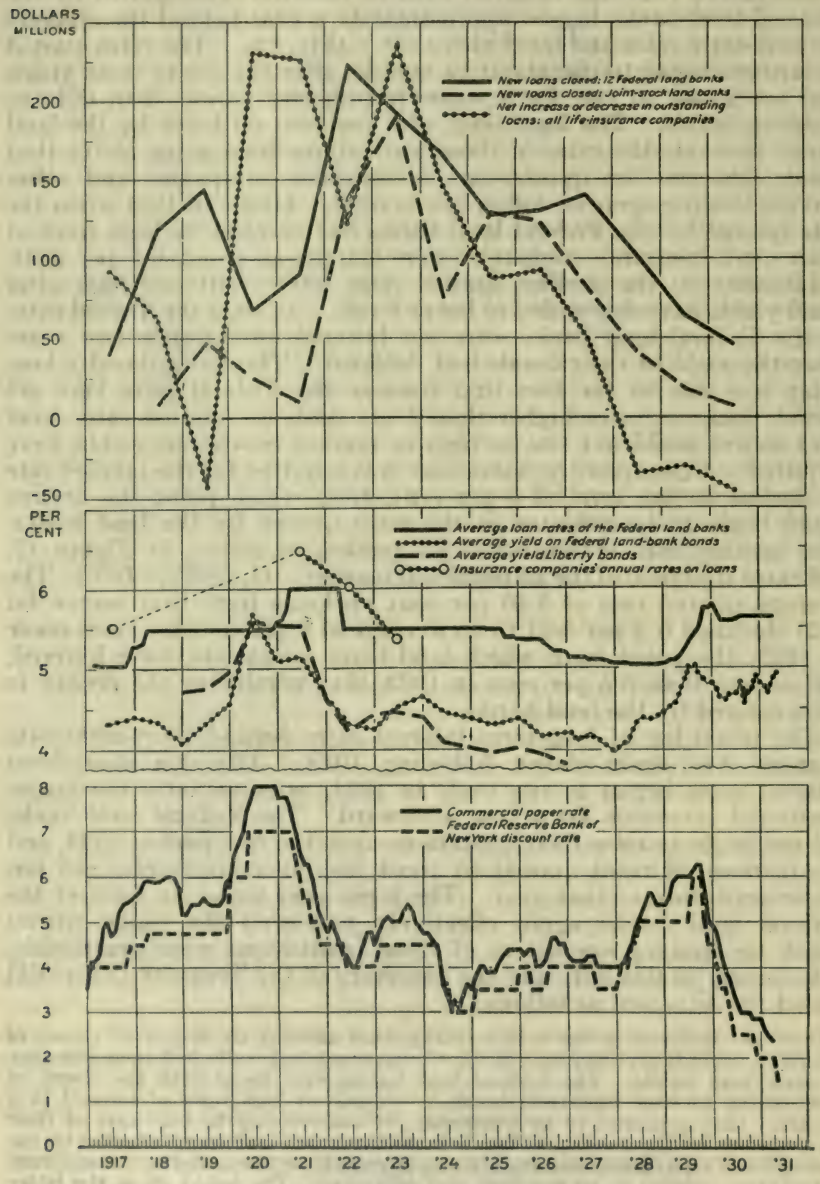

FIGURE 12.—SHORT-TERM INTEREST RATES, BOND YIELDS, FARM-MORTGAGE RATES, AND VOLUME OF LOANS

The close relation of commercial-paper rates and discount rates at the Federal Reserve Bank of New York from 1917 to 1930 is apparent. Yields on Federal land-bank bonds and Liberty bonds conformed to the general course of short-term rates though with less variation, while rates quoted on farm mortgages by the Federal land banks and insurance companies lagged behind from 12 to 18 months following 1920 and 1928. The changes in annual volume of loans made by those agencies was partly in response to the money-market conditions. (The low volume of loans of the Federal and joint-stock land banks during 1920 and 1921 was due largely to suspension of operations pending litigation.)

After the break in the stock market in the fall of 1929 and after short-term rates had begun to decline, bond yields were much slower to change and quoted rates on farm mortgages continued at high levels. Wise credit management requires that a farmer recognize the existence of this lag in farm-mortgage interest rates in arranging his finances.

EFFECT OF MONEY-MARKET CONDITIONS ON SUPPLY OF MORTGAGE FUNDS

Periodic shortages of funds incident to high rates may affect farm-mortgage financing in various ways. Commercial banks or other local sources may send funds to loan on the call market which usually offers specially attractive rates at such times. If the security markets are active, individuals may use their surplus funds to buy

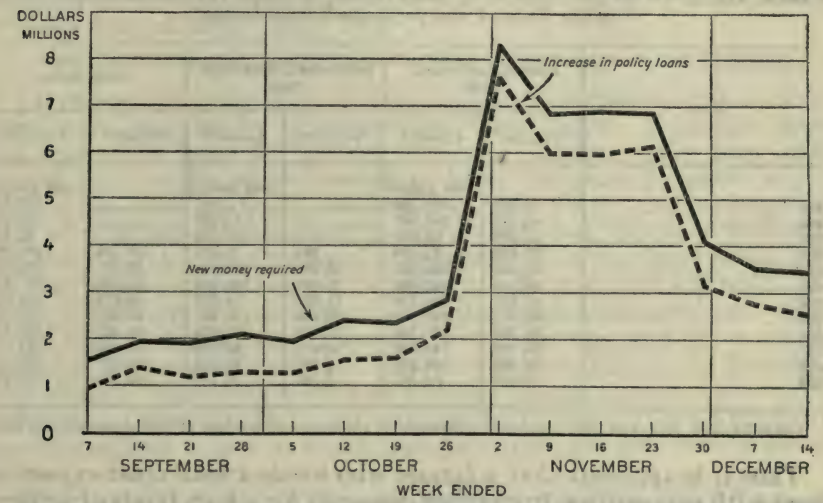

FIGURE 13.—TOTAL NEW MONEY REQUIRED FOR POLICY LOANS AND INCREASE IN OUTSTANDING POLICY LOANS OF 13 COMPANIES SEPTEMBER 2 TO DECEMBER 14, 1929

The competition that farmers meet in obtaining mortgage loans during a period of money stringency is indicated by the great increase in the volume of loans to policyholders in life insurance companies during the break in the stock market in October and November, 1929. The usual uniform stream of funds available for investment by these important lending institutions was partly diverted to meet the prior claims of many policyholders. These 13 companies have in force approximately 22½ per cent of the total ordinary insurance in force in the United States

stocks. Agencies dependent upon sales of bonds for loanable funds, such as the Federal and joint-stock land banks, and the State loan systems, may be unable to sell their issues at practicable rates, or may be so restrained by legal limitations of the loaning rate that they are kept out of the farm-loan market. Such funds as may become available through receipt of loan payments may be used more profitably to purchase bonds previously issued, but whose current price offers favorable opportunities to reduce the bank's outstanding interest-bearing bonds. Insurance companies have the same alternative of buying greater proportions of bonds at low prices. In addition, they may be faced with the necessity of making large advances to their policyholders to tide over emergencies such as occasions when the stock market breaks and added sums are needed to maintain margins (*4*). This item amounted to a substantial demand on the funds of life insurance companies during the fall months of 1929. (Fig. 13.)

Reference to Figure 12 discloses several instances during the last decade when the supply of mortgage funds was affected in one or more of the ways indicated. Farm-mortgage investments by insurance companies fell very low in 1919 when large quantities of Government bonds were being offered. Again, in 1922, following the high yield of Liberty bonds and the selling of great amounts of these securities held by individuals, the farm-mortgage investments of insurance companies declined. In 1923, however, following a period of low bond yields, farm mortgages were greatly emphasized as investments despite heavy competition from the land banks. In 1924 when rates and bond yields remained high, the volume of insurance loans again slackened, as was true of loans by the joint-stock land banks. (Table 31.)

TABLE 31.—*Number and amount of loans closed, by years 1918 to December, 1929, by the Federal and joint-stock land banks*

Year	Federal land-bank loans		Joint-stock land-bank loans		Total loans	
	Number	Amount	Number	Amount	Number	Amount
		1,000 dollars		*1,000 dollars*		*1,000 dollars*
1918	49,808	118,130	----------	[1] 7,381	----------	125,511
1919	45,436	144,987	----------	[1] 47,306	----------	292,293
1920	17,997	66,985	----------	[1] 23,272	----------	90,257
1921	27,153	91,030	881	9,335	28,034	100,365
1922	74,055	224,301	15,916	138,685	89,971	362,986
1923	60,100	192,083	27,433	189,748	87,533	381,831
1924	47,227	165,510	11,390	74,587	58,617	240,097
1925	39,905	127,355	19,699	131,431	59,604	258,786
1926	36,893	131,318	19,928	123,026	56,821	254,344
1927	39,268	140,384	14,088	82,328	53,356	222,712
1928	26,988	102,236	7,299	40,572	34,287	142,808
1929	17,132	64,252	3,107	18,186	20,239	82,438

[1] Loans for 1918, 1919, and 1920, represent differences in amounts outstanding at end of successive years.

Thus it is apparent that a farmer who needs a loan must expect to meet with competition from other demands for which funds of lenders may be used. So far as possible he should avoid the necessity of long-time financing during short-term money crises or at such other times when alternative demands make his problem more difficult.

NEED FOR FARMERS' ATTENTION TO FINANCIAL MARKETS

Farmers who have mortgage financing in prospect may well take warning from rises in short-term money rates and bond yields as an indication of higher rates likely to follow on mortgages made six months or a year later, and frequently of a reduction in the available supply of funds for mortgage purposes. The shorter the term of the mortgage loan the more frequently will this precaution have to be taken. In loans of very short terms, refinancing at favorable rates may require a material shortening of the original term and consequently a greater interest cost per annum for the term actually used. Long-term loans with repayment privileges reduce the frequency of the problem and afford more opportunity for choosing a favorable time in which to arrange for the loan to be carried.

A farmer should recognize the fact that his financing operations are a part of the finances of the whole country and may even be affected by the finances of other countries. He may be favorably or adversely affected by developments in the general business community which show their results in the money centers. Consequently he must

acquaint himself with the current position and trends of the money market, he must learn what the prevailing interest rates are on standard classes of paper and on farm mortgages and must observe the direction in which they are moving.

Unfortunately such information has not always been readily available to the farmer, nor has it always been sought. Many farmers who have grain or livestock to sell are accustomed to watch those markets closely. But if a mortgage is to be taken out or renewed, they may give little or no attention to the condition of the money market far enough in advance of the time the loan has to be made to profit by the information. An indication of the need of using such information is the greater volume of farm mortgages that were made when rates were high, especially in 1920 to 1921 and 1923 to 1924, thus placing the average rate of the financing of agriculture on a level above the average market rate. (Fig. 12.)

TENDENCY TOWARD HEAVIER BORROWING DURING HIGH-RATE PERIODS

An important proportion of farm mortgages originate from borrowings from local banks or other short-term loans. Typically these are short-term loans for various purposes, but frequently they arise out of the transfer of real estate or loans for other purposes which have been met by loans secured by real estate. An average of 11.3 per cent of all loans made by the Federal land banks to 1929 had been obtained for the purpose of paying other than mortgage debts, and 65.9 per cent were used to pay mortgages. In turn, many of the mortgages taken over also represent an earlier funding of accounts. The local bank holds a close relation to the farmer, and its business includes the rendering of such loan accommodations as its resources will permit. The bank's services thus tend to give rise to a stream of obligations, most of which are repaid by the proceeds of the borrower's operations, but a part of which, are paid from the proceeds of mortgages funding the original debt.

When credit cost and demand are moderate, financing tends to remain in the local community. Whenever interest rates rise materially in the central money markets, money from correspondents and even funds of individuals tend to flow to such centers rather than to continue available as loans or deposits to local banks for meeting the demands of customers. As the bank's resources become inadequate for meeting current requirements it encourages farmer borrowers on older accounts to liquidate obligations to the bank by taking out a mortgage with some other agency, usually one specializing in that type of loan. Other prospective borrowers of the bank obtain directly by mortgage funds which, under usual rate and supply conditions, they would have obtained from the bank. Thus a rise in short-term money rates tends to be followed some time later by a rise in the demand for farm-mortgage loans.

Meanwhile the higher short-term rates become reflected in higher long-term rates. Agencies that obtain their funds for mortgage loans through bond issues find that they must compete with higher short-term rates prevailing. Agencies that receive streams of funds from current contributions, such as life insurance companies, are able to employ such funds at higher rates of return than they have been getting from farm mortgages. The agencies using bond issues as a source of funds can continue operations for some time by using the

proceeds of earlier issues. Eventually, however, if they are to continue loaning they must issue bonds that bear higher rates, and the rate to the borrower must be raised to a level that will permit payment of the new bond rate plus operating costs.

Other agencies also continue loaning at the old rates for some time while applications in process are being acted upon and while other investments are becoming of more attractive yield. When these higher rates become generally available and competition will permit, mortgage rates are increased and local representatives are notified to negotiate new loans on the higher basis after a certain date.

The net result of these proceedings, incident to a rise in short-term interest rates, is a simultaneous lag in rates and volume of mortgage financing which tends to produce a dominance of farm mortgages bearing rates higher than the average prevailing over a period of years, and above the rates that would be carried by loans obtained in uniform amount through the same length of time. Although such mortgages may bear, on long-term loans, rates below those on the local indebtedness they have replaced, the mortgage rate may still be above average.

There seems to be no such compensating movement when rates are low. During periods of low rates the money supply, in rural areas, is likely to be adequate, barring local misfortune, so that local agencies can meet most of the farmers' current demands by means of short-term loans. Hence there is not the forced funding which characterizes high-rate periods. Refunding of the mortgage offers a partial escape from this situation, but if the new loan is to have a short term of years, the renewal cost may equal the saving in interest. For many farmers the best means of avoiding such difficulties is to take out a long-term loan when the conditions of interest rates and fund supply are favorable.

FARMERS' ALTERNATIVE METHODS OF FINANCING

During periods of high money rates, as at other times, a farmer does not have the financing alternatives of larger industrial business, which may sell its short-term notes in the market or raise capital by sale of stock to the public and thus acquire needed capital without borrowing at high rates. Sales of stock may even be used to redeem at low prices bonds previously issued (*1*). Usually the farmer can not employ short-term borrowing for all of his needs until more favorable long-term rates return. Local banks that usually constitute his principal source of short-term credit, are often unable to loan the amounts needed. Mortgages that fall due in such years are often too large to be carried even temporarily by local agencies. It is not practicable to sell an interest in his farm by issuing stock and yet retain control over the whole as a corporation may do. Usually he can not dispose of a part of the farm without impairing the effectiveness of the remainder as a working unit. If he has need of additional capital he must borrow on his own security and contract to pay the rate of interest current at the time.

The great part of the farmers' financing thus tends to take the form of mortgage on real estate. In the past, the proportion has been approximately 75 per cent mortgage and 25 per cent short-term loans. The share of fixed obligations has become larger in recent years as mortgages have increased and total short-term loans in the agricultural districts have greatly declined.

In contrast, the credit of industrial business during high-rate periods has been conducted mainly on a short-term basis. A larger amount of property in the form of goods in process or assets that can be readily converted into cash facilitates the more prompt retirement of such obligations than is possible from the annual production of agriculture. In 1925, manufacturing corporations had only one-third of their borrowings in the form of mortgages and bonds, while two-thirds were notes and accounts.

Figure 14 indicates the relative volume of farm-mortgage financing at different interest-rate levels from 1920 to 1929, in comparison with the varying proportions of the financing of domestic corporations supplied by different methods during the same period. The annual volume of farm-mortgage loans reached its peak in a period of high interest rates—1923 to 1924—so that the bulk of loans made at that time carried on through their terms at the higher rates which then prevailed.

During the same years domestic corporations followed a general policy of issuing bonds when interest rates were low and of selling stock and short-term notes when rates were high. Long-term fixed obligations or bonds averaged only 35 per cent of their total financing, preferred stock 5 to 15 per cent, short-term notes less than 10 per cent, and common stock in the company the remainder (*1*). The benefit from greater variety of financing alternatives possessed by the industrial concern, partly because of size, corporate form, and financial facilities, is evident. Under existing facilities the farmer's nearest approach to equally advantageous financing is by means of a long-term mortgage taken out when money conditions are advantageous.

MANAGEMENT OF FARM-MORTGAGE CREDIT

LONG-RUN ASPECTS OF FARM MORTGAGES: IMPORTANCE OF LOAN TERM

Problems of farm-mortgage finance are both of immediate and of long-term nature. The short-term considerations are concerned with the availability of funds for loans wanted at a given time and the negotiation of favorable interest rates and other terms on such a basis as will probably permit desirable handling of the loan during the several years following.

The long-term aspect requires consideration of consequences that are likely to follow during a considerable period of years as a result of the existence of the mortgage in relation to the production and earnings of the farm, and to changes in the price level. The problems arising out of this second aspect neither fully appear nor can be dealt with in a short period of time, save as they can be foreseen and avoided.

The problem is, therefore, one of prevention rather than correction. A mortgage of such nature that the farm income will not meet current interest cost or the amount of which reflects a large proportion of the purchase price of a farm bought during a period of extremely high price level, is likely to have long-term consequences of operation at a loss and the possible sacrifice of the property.

TERM OF AVERAGE FARM-MORTGAGE DEBT

The necessity of facing the long-term consequences of mortgage debt is evident from a consideration of the continuous term of the individual farmer's occupancy. Typically the farm owner does not

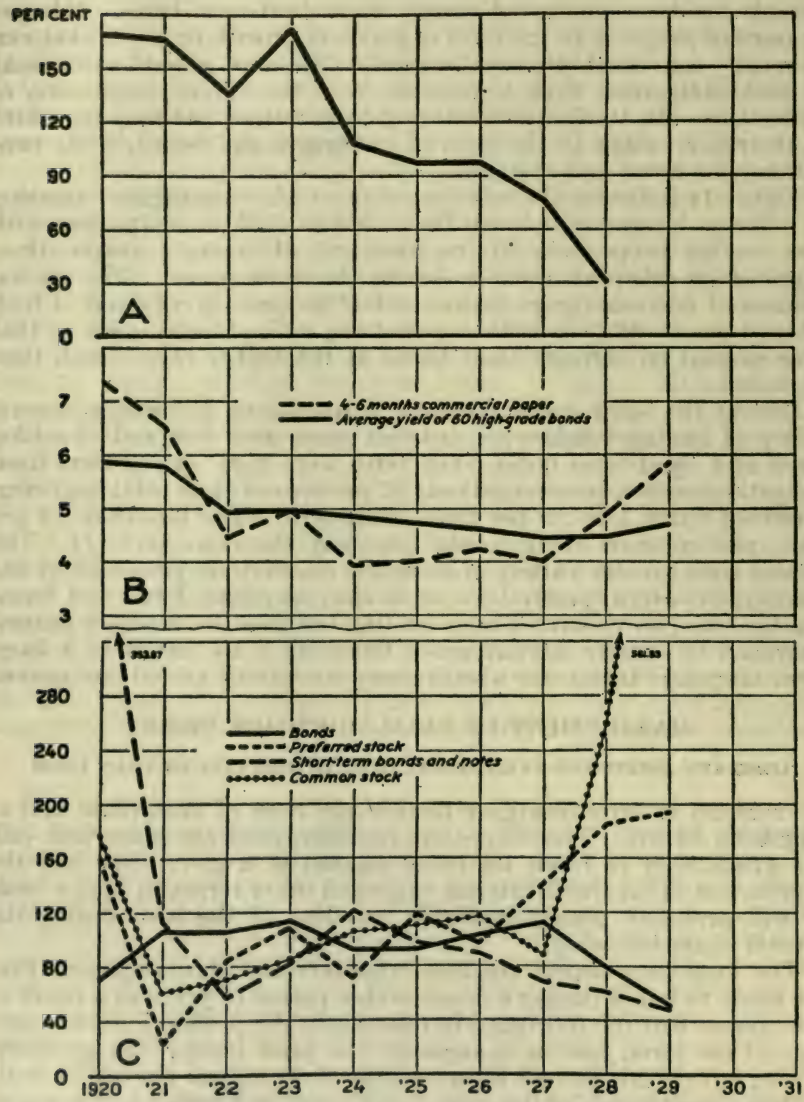

FIGURE 14.—COMPARISON OF FARM-MORTGAGE FINANCING WITH CORPORATE DOMESTIC FINANCING IN RELATION TO INTEREST RATES AND BOND YIELDS

A, Farm-mortgage financing index annual amount of new mortgages by insurance companies Federal land banks and joint-stock land banks, 1920–1928=100 (1920-21 insurance companies only); B, interest rates and bond yields; C, corporate domestic financing index of percentages of total amount by types of financing 1923–1925=100.

There is a tendency for more mortgages to be taken during years of high interest rates than during years of low interest rates due in part to funding of other loans necessitated by the pressure on banks and individuals at such times. This policy contrasts with the financing methods of corporations (C) which use short-term borrowing, or sell stock to the public when interest rates are high and issue bonds to take up their high-cost credit when interest rates are low.

change farms and does not pay off any mortgage that may exist. The debt when once acquired continues on the farm as an extended or renewed loan. The necessity of looking to the future in mortgaging is more apparent when the average term of mortgage loans is compared with the much longer period of years during which the mortgaged farmer remains in debt.

The reports of farmers regarding the presence or absence of debt on their farms at different dates provides a basis for computing rates of acquiring and paying off mortgages. (Table 32.) The rate of incurring mortgage taken in connection with the total percentage of farms having such debt indicates an average period of about 25 years that such farms would remain under debt if their mortgages had been incurred at the same rate as that during the years 1925 to 1928. The rate at which farms are cleared of debt, however, is a more accurate indicator of the length of time that the average farm is likely to remain under mortgage. The practice of renewal rather than repayment has long been the rule rather than the exception with the farm mortgage. Applying this annual rate for 1925 to 1928 to the total percentage of indebted farms in 1928 discloses an indication that the average mortgaged farm will remain in debt for about 35 years, varying from 23 to 50, among the geographic divisions. An average of the two rates, which would allow for some fluctuations in both rates, indicates that under the conditions prevailing during recent years the average mortgaged farm will carry indebtedness for at least 30 years. By coincidence this period is nearly as long as the standard term of the amortization loans made by the Federal land banks and the joint-stock land banks, and other loan plans whereby annual payments of about 1 per cent of the principal retires the debt during a term of about 33 or 34 years.

TABLE 32.—*Average number of years mortgaged farms remain under mortgage, computed on basis of rate at which new mortgages were incurred, and rate at which mortgaged farms were cleared of debt, 1925–1928*

Geographic division	On basis of rate at which new mortgages were made			On basis of rate mortgages were paid off		Average term of debt [4]
	Rate at which farms become mortgaged [1]	Percentage of all farms having mortgage debt [1]	Average period farms remain mortgaged [2]	Rate at which mortgaged farms were cleared of debt [1]	Average period farms remain mortgaged [3]	
1	2	3	4	5	6	7
	Per cent	*Per cent*	*Years*	*Per cent*	*Years*	*Years*
New England	0.86	32.8	38.1	1.00	32.8	35.4
Middle Atlantic	1.15	31.1	27.0	.97	32.1	29.6
East North Central	1.32	38.3	29.0	.89	43.0	36.0
West North Central	1.22	49.2	40.3	.99	49.7	45.0
South Atlantic	1.54	26.0	16.9	1.12	23.2	20.0
East South Central	1.38	26.4	19.1	.98	26.9	23.0
West South Central	2.04	38.7	18.9	1.14	33.9	26.4
Mountain	1.29	45.1	35.0	1.40	32.2	33.6
Pacific	1.59	45.0	28.3	1.23	36.6	32.4
United States	1.45	36.0	24.7	1.03	34.6	29.6

[1] Average 1925–1928 expressed as per cent of all farms.
[2] Column 3÷column 2.
[3] Column 6÷column 5.
[4] Average of columns 4 and 6.

If the reports on this item for the period 1925 to 1928 are typical of mortgage practice, the results indicate that most farmers would save inconvenience and expense by taking out mortgages that have terms much longer than are now covered by most loans. This will not apply, of course, to those cases in which the owner will need the funds for only a short term and is able to care for the loan at the end of its term. In most instances, however, farmers who contract for mortgages with 5-year terms should realize that before the debt is paid they will probably have to make at least four or five renewals, with a greater or smaller number of renewals if the term is less or more than five years.

The desirability of longer terms is further indicated by the practical difficulty of paying off a loan of the average size within a short period of years. If the average net worth of full-owner farmers in 1925 is taken as approximately $6,700, and the number of years as a farm operator is taken as 20, the average annual rate of accumulation during the 20 years prior to 1925 was $338. This assumes that all of the owner's wealth was acquired during his years as a farm owner or tenant although as a matter of fact owners as of 1920 averaged over two years as wage earners before becoming owners and may be expected to have accummulated some money when they began to farm for themselves. Furthermore, this figure makes no allowance for capital received by inheritance.

If the average mortgage on full-owner farms in 1925 is apportioned to the size of the average of such farms, it is found to be $3,059. If the whole of the $338 average annual gain were applied to the reduction of this average debt, it would require nine years to pay off the debt, a period much longer than the terms of most mortgages. As a matter of fact, it is usually not possible to apply all gains to reduction of debt. A portion of the annual accumulation often takes the form of improvements; often the earnings are used to expand the farm business or to add equipment for more efficient farm operation.

TERM OF FARM-MORTGAGE LOANS

The long-term persistence of indebtedness on a farm when it is once mortgaged contrasts with the relatively short terms of the great majority of mortgages; long-term loans are the exception and not the rule.

A distribution of loans by length of term as reported by leading agencies for 1924 indicated that 17.5 per cent of the outstanding loans had a term of 1 year; 11.7 per cent, 2 to 4 years; 46.5 per cent, 5 years; 9.6 per cent, 10 years; and 13.2 per cent had terms of more than 30 years. Mortgage companies had 75 per cent of their loans on 5-year terms and insurance companies 65 per cent. The fact that commercial banks had 52 per cent of their farm mortgage loans on terms of one year suggests the frequent renewals that many farmers have to arrange. (Table 33.)

TABLE 33.—*Length of term of farm-mortgage loans: Percentage distribution of holdings of principal lending agencies* [1]

Agency	Average term	Percentage of loans for—					
		1 year	2 to 4 years	5 years	10 years	11 to 30 years	Over 30 years
	Years	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Insurance companies	5.6	4.4	13.3	64.8	14.6	2.5	0.4
Federal land banks	33.0	------	------	------	------	------	100.0
Joint-stock land banks	33.0	------	------	------	------	------	100.0
Commercial banks	2.6	52.1	19.9	26.7	.7	.6	------
Mortgage companies	6.2	.3	2.8	74.5	20.6	1.8	------
Other sources [2]	4.7	20.1	13.5	53.6	11.1	1.7	------
All agencies	8.5	17.5	11.7	46.5	9.6	1.5	13.2

[1] Data as of Jan. 1, 1924.
[2] Computed from reports of other than land-bank sources.

REFINANCING AS A FARMER'S PROBLEM

Aside from the long-term amortization loans principally made up of the loans of the Federal and joint-stock land banks, other loans on farm mortgage average less than five years in term. (Table 33.) This means that each year approximately a billion and a half dollars of farm-mortgage loans must be renewed or otherwise refinanced. New financing seldom has amounted to more than one-fifth of the total farm-loan operations in a given year.

The necessity of the remaining large annual volume of refinancing is predetermined by the fixing of the due date in the original loan contract. Consequently the new loan contract must be undertaken under whatever conditions prevail at that time, even though a shortage of funds or a period of high interest rates may be encountered. Meanwhile, the farmer must meet the competition from a total of $6,000,000,000 to $10,000,000,000 in new bond and stock issues offered annually to the public. In other words, the regular recurrence of the necessity of readjusting old debt gives the farmer a disadvantage in the management of his finances. The privilege of prepayment is not included in many loan contracts though it may often prove a valuable provision.

Refinancing of existing loans thus raises a problem for both borrower and lender. Neither may be able to foresee what money-market conditions will be three or five years hence. Although lending agencies have an alternative use for funds when rates are high, a farmer does not have alternative methods of financing. His best recourse will usually be the avoidance of the danger by observing the movement of short-term rates.

HEAVY LOANS AN OBSTACLE TO BEST FINANCING

Improvement in the type of loan obtained by farmers is retarded by the large number of cases which have debt ratios in excess of the loaning limits of agencies offering long-term amortized loans. Data indicate that mortgages assumed on transferred farms average nearly two-thirds of the value of the farm, and that the same farms have had approximately that amount of debt before being transferred.

The extent to which existing indebtedness has become a barrier to improved financing is indicated by the fact that in a single year one

of the Federal land banks had applications for over $10,000,000 in loans, but because of inadequate security in most cases made actual loans of only about $3,500,000 (*8*). This experience is probably typical of the demand for loans made upon many lending agencies.

Although an agency may be willing to loan the greater part of the amount applied for, the problem of caring for the additional debt, which can not be included in the first mortgage, and the frequent difficulty of obtaining second mortgages often combine to prevent the farmer from obtaining even a part of the debt refunded as desired. Moreover, if the borrower has other indebtedness in excess of what may be loaned on his land, this fact often is taken to indicate an undue interest burden, which may lead to difficulty even with a first-mortgage loan.

RELATION OF AMOUNT OF LOAN TO POSITION OF PRICE LEVEL

In a farmer's management of his mortgage credit the current position of the price level is important. Neglect of this item may have far more serious results than indifference to other phases already mentioned. He may give successful care to the source, interest rate, term, and method of repayment, yet if the current price level is not considered when the amount of the mortgage is determined, the advantage of all other precautions may be lost, and even foreclosure may occur.

The discussion of the average duration of the period of encumbrance has indicated that whether the term of the mortgage is long or short, the average debt itself continues in some form for 25 to 35 years or longer. The farmer who contemplates placing a mortgage on a farm that he wishes to keep or to pass on to his heirs, therefore, must view the loan obligation as it is likely to develop over the following two or three decades. In so far as possible, the amount of the loan as well as all of its conditions should be such that payments can be made or the mortgage renewed and the property held regardless of changes likely to occur in the level of general prices.

During the period of high prices, 1918 to 1921, prices of land followed the general upward trend though at a somewhat lower level. Many borrowers and lenders erroneously assumed that the higher price level then current would continue high permanently or at least for a long time. In an investigation made in 1919 Lloyd (*11, p. 363*) reported:

> Generally speaking bankers and farmers were optimistic that the price of land would be maintained or would advance. They believe that present prices of farm products will continue for a few years.

Farm mortgages incurred at that time were generally made with reference to current land values and so represented amounts substantially larger than usual.

This tendency for the size of new loans to conform to the current value of the land is illustrated by the average amount of the loans obtained by farmers from the Federal land banks and joint-stock land banks during each year of operation for those institutions. Figure 15 shows the index of the average size of loans plotted on the same scale as the index of land values. After a lag of one year during 1917 the size of loans by the Federal land banks rose rapidly following the upward course of land values to the peak in 1920 and then down to

1922.[13] The sharply downward trend continued for a year after 1922, similar to the lag on the rise, and then followed a more gradual decline close to that of land values. These loans were all made under the standard loaning provisions of the land banks, which limit loans to 50 per cent of the value of land and 20 per cent of the value of improvements, hence they did not include purchase-money mortgages, arising out of transfers, which frequently represent higher proportions of the land value.

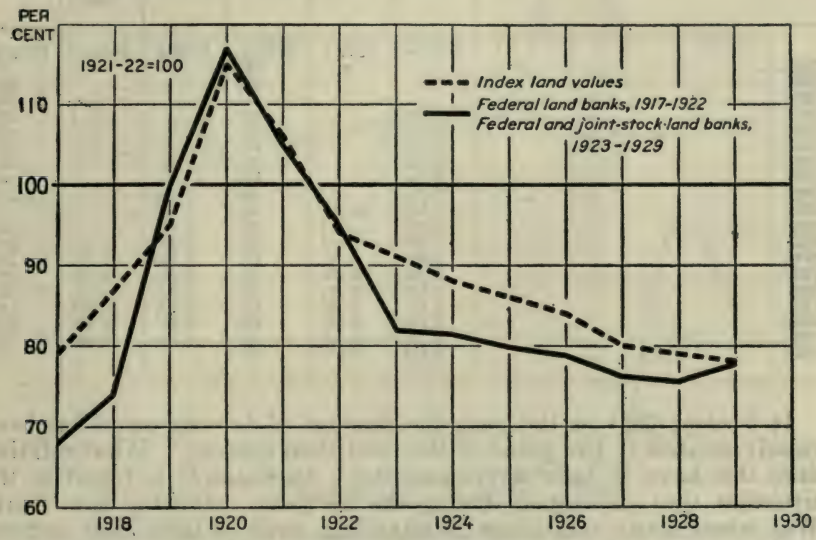

FIGURE 15.—INDEX NUMBERS OF AVERAGE SIZE OF LAND-BANK LOANS AND OF LAND VALUES

The influence of the price level on the amount of money borrowed is indicated by the close relationship between the index of average size of land-bank loans and the index of land values from 1917 to 1929.

The same tendency for the loan to reflect the current price level is shown by the average size of mortgages made by the Minnesota Rural Credit Commission; the amount of the loan steadily declined from an average of $5,344 for the first year of operation, 1923–24, to an average of $3,893, in 1928–29. In Nebraska, the average size of mortgages filed conformed closely to land-value trends although including second mortgages and purchase-money mortgages incident to land sales. The size of second mortgages revealed the same tendency, as shown by column 3 in Table 34.

[13] Note on Figure 15 and Table 34: An amendment to the Federal farm loan act in 1923 extending the Federal land bank's loan limit from $10,000 to $25,000 resulted in interactions in size of loans from Federal and joint-stock land banks thereafter. Because of that fact the trend of loan size thereafter is shown in Figure 15 by an average of the size of loans from the two sources. Data for number and amount of loans made by the joint-stock land banks are not available for years earlier than 1921. The two series were, therefore, linked together for 1922 and carried on with the relative difference shown for that year.

TABLE 34.—*Average size of loans made by four representative agencies, and in Nebraska, by years, 1912 to 1930*

Year	Average mortgage loans					Index of land values
	Federal land banks	Joint-stock land banks	Jewish Agricultural Society	Loans filed in Nebraska	Minnesota Rural Credits Commission	
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Per cent*
1912			625			97.0
1913			570			100.0
1914			564			103.0
1915			455			103.0
1916			571			108.0
1917	2,154		546			117.0
1918	2,372		565			129.0
1919	3,191		699			140.0
1920	3,722		916	7,128		170.0
1921	3,352	10,596	768	5,706		157.0
1922	3,029	8,714	710	5,167		139.0
1923	3,196	6,917	727	5,437		135.0
1924	3,505	6,548	623	5,740	5,344	130.0
1925	3,191	6,672	618	5,675	4,777	127.0
1926	3,559	6,174	632	5,867	3,834	124.0
1927	3,575	5,844	647	5,200	3,832	119.0
1928	3,788	5,557	616	5,167	4,263	117.0
1929	3,751	5,853	599	5,045	3,893	116.0
1930	3,816	5,957	481			115.0

It is clear that in the past the amount of debt incurred has been closely related to the value of the land then current. What relation does this have to later developments? An example is found in the situation that developed during the 10 years following the World War when many mortgages outstanding were so large that farmers could not meet the payments, and lenders could neither continue to carry the loans nor renew them for the original amount. The result has been the loss of many farms which the owners wished to keep, and the acquisition of much land by lending agencies which they did not want, a condition distressing to both borrower and lender and one that probably would have been avoided had such consequences been foreseen when the mortgages were made.

The general disregard of price-level changes not only results in a marked increase in mortgage debt during the period when prices are at their peak, but also in further additions to the debt burden for a number of years thereafter. Despite the steady price decline following 1920 and large reductions from foreclosure and reversion, the mortgage debt of the country was nearly 20 per cent larger in 1928 than in 1920. Apart from the increases due to funding short-term loans into mortgages, heavy indebtedness itself often becomes a cause of added debt, for whenever the debt ratio exceeds the cost-yield ratio, the excess carrying charge becomes a further encroachment on the farm capital.

THE AFTERMATH OF PRICE DECLINES

The consequences of price declines are partly indicated by foreclosures, bankruptcies, and bank failures. (Fig. 16.) The course of these misfortunes in relation to the wholesale price index since 1890 shows that low points in the price curve were reached in 1896 and 1921. The low point of 1896 was the culmination of a long period of

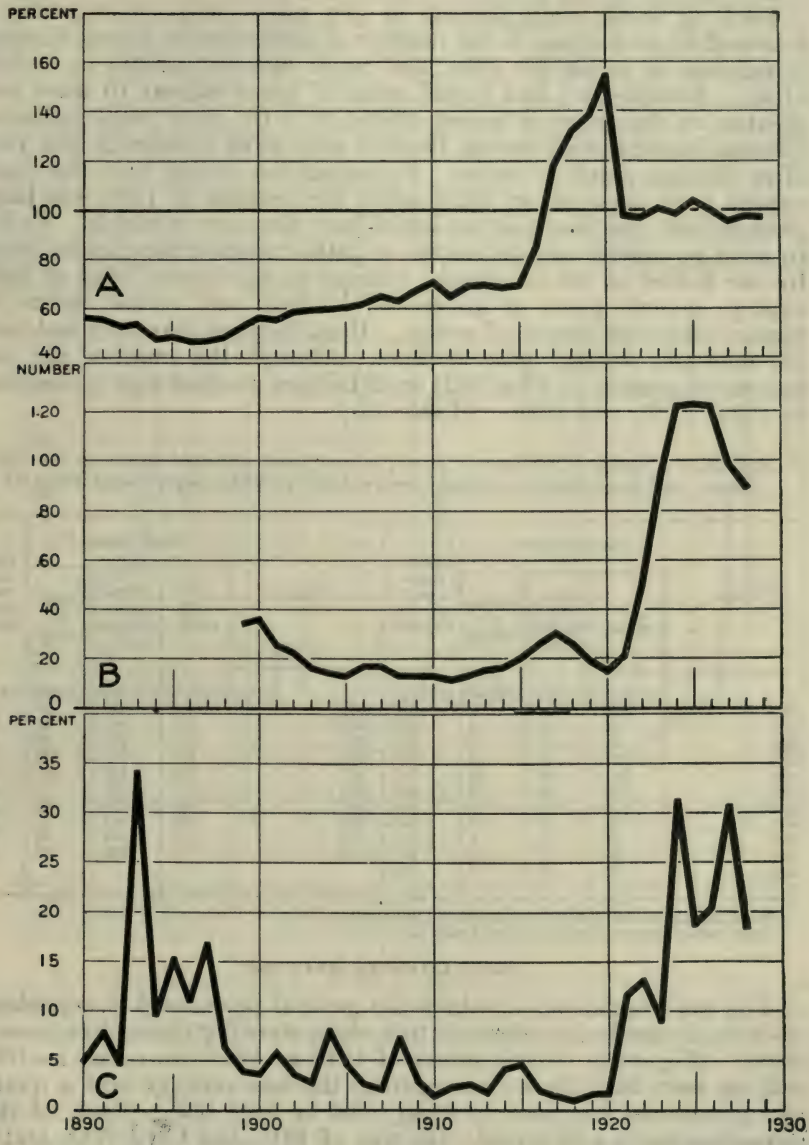

FIGURE 16.—PRICE CHANGES, FARM BANKRUPTCIES, AND BANK FAILURES, IN THE UNITED STATES

A, Index numbers of wholesale prices, 1926=100; B, farm bankruptcies per 1,000 farms; C, bank failures per 1,000 banks in operation. The danger of incurring heavy obligations during periods of high prices is shown by the greatly increased number of bankruptcies among farmers and of bank failures which have followed each such price peak. The largest percentage of farm bankruptcies during the last 30 years occurred in 1900 and in 1925—four years after the low price years of 1896 and 1921.

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falling prices, and 1921 marked the collapse of the inflated war prices which had reached a peak in 1920.

Each of these main periods of low prices was accompanied or followed by an increase in the number of bankruptcies among farmers, foreclosure of farms for debt, and bank failures, mostly in farming areas. Foreclosures and forced sales of farms appear to have been greatest in the years of lowest prices or in the next years following, whereas bankruptcies among farmers were most numerous four years after the low point in prices. Following the World War this bankruptcy peak occurred in 1925, while the number in 1900 was larger than in 1899, the first year for which such data are available. Failure to meet payments usually results in rather prompt foreclosure action by the holder of the mortgage, whereas in the typical case of bankruptcy, several years of unsuccessful effort may elapse before the farmer takes this course of action. Bank failures also have had notable increases during price declines, although the number per year has varied greatly. After 1921 such failures reached high proportions in 1924, 1927, and 1930. (Table 35.)

TABLE 35.—*Number of failures of State, private, and national banks in the United States, and bankruptcies among farmers 1910–1930 by years ended June 30*

Year	Bank failures [1]			Bankruptcies [2] among farmers	Year	Bank failures [1]			Bankruptcies [2] among farmers
	All banks	State and private banks	National banks			All banks	State and private banks	National banks	
	Number	*Number*	*Number*	*Number*		*Number*	*Number*	*Number*	*Number*
1910	34	28	6	849	1921	358	330	28	1,363
1911	58	55	3	679	1922	396	363	33	3,236
1912	63	55	8	837	1923	274	237	37	5,940
1913	45	40	5	942	1924	915	777	138	7,772
1914	115	96	19	1,045	1925	542	440	102	7,872
1915	126	110	16	1,246	1926	573	496	77	7,769
1916	56	41	15	1,658	1927	831	689	142	6,296
1917	41	35	6	1,906	1928	484	413	71	5,679
1918	28	25	3	1,632	1929	549	482	69	4,939
1919	45	43	2	1,207	1930	640	558	82	4,464
1920	49	44	5	997					

[1] From annual reports of the Comptroller of the Currency (*23*).
[2] From annual reports of the Attorney General.

PRICE CHANGES SINCE 1800

The wide variations of which the general price level is capable are seen most clearly by reference to a chart showing these changes since 1800. (Fig. 17.) If the prices of 1910 to 1914 are taken as 100 it will be seen that three times during the last century and a quarter the price level has risen to nearly 200 or over (*22*). Each of these occasions was a war period—the war of 1812, the Civil War, and the World War. The future course of prices can not be determined, nor can it be known whether any future event will again raise prices to the high levels occasionally reached heretofore. It is important to observe, however, that the character of these high price periods in the past has been distinctly different and that whenever high levels have been reached, prices have declined greatly within the years immediately following. The inevitable consequence in each case has been that obligations incurred at the high price levels have caused much difficulty in repayment later.

DANGER FROM MORTGAGES ARISING OUT OF PURCHASE OF LAND

Although all monetary obligations incurred during periods of high prices are open to the objection that they may have to be paid with dollars of greater purchasing power, the danger is especially great when the debt represents a large proportion of the value of the property. In the case of first mortgages obtained from special mortgage agencies, the usual rules restricting loans to a conservative proportion of the farm value provide some protection to the farmer against the danger of the debt ratio becoming too high. If the debt is restricted to approximately half the value of the farm, a decline of one-half in prices would still leave the sale value as great as the debt and the farmer could continue in possession of his farm as long as he could renew the loan and meet interest payments.

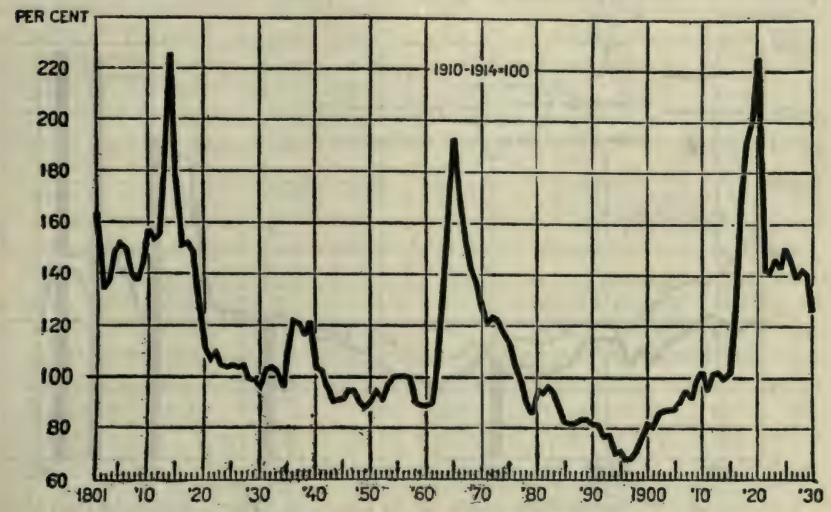

FIGURE 17.—INDEX NUMBERS OF WHOLESALE PRICES, 1801 TO 1929

Three times since 1800 prices have risen to very high levels—in 1814, 1865, and 1920. After each of these peaks prices have fallen sharply and then more gradually for a period of years. Debt incurred during these periods of high prices has been repayable under the difficulty of using dollars of greater purchasing power and product returns of less debt-paying power.

In the case of mortgages given in purchasing farms, however, often involving a second as well as a first mortgage the danger is much greater. Such indebtedness usually averages two-thirds of the value of the farm and often constitutes even higher proportions. Therefore early in the decline in prices the land value is equaled by the debt. With farm returns often yielding less than the interest rate, a debt of two-thirds or three-fourths of the value of the land may consume the entire return from the land.

Although periods of extremely high prices occupy only a few years as compared with the longer intervening periods of gradual change transactions conducted on high price levels are relatively more numerous because of greater activity in land transfers and other dealings resulting in the use of credit. Debts contracted under these conditions may cause much difficulty in later years when they must be paid with dollars of greater purchasing power.

RELATION OF CROP VALUE, PRICE LEVEL, AND DEBT-CARRYING CAPACITY

A comparison of the course of the price level since 1866 with the per-acre value of 10 leading crops [14] shows a general relationship throughout the period. When the index of average mortgage debt per acre for all full-owner land is plotted on the same chart, a close correspondence between debt and prices is shown from 1890 to 1920. After 1920 the debt burden continued to even higher levels while the dollar value of crop returns fell off sharply. Figure 18 indicates the wide disparity that occurred between obligations and the means with which to meet them as a result of debt incurred at high price levels.

How then may the farmer judge as to the safe limits for mortgages given? How may the lender on mortgage security assure the safe return of his funds without taking the property? Answers to these questions depend primarily upon two considerations—the amount of

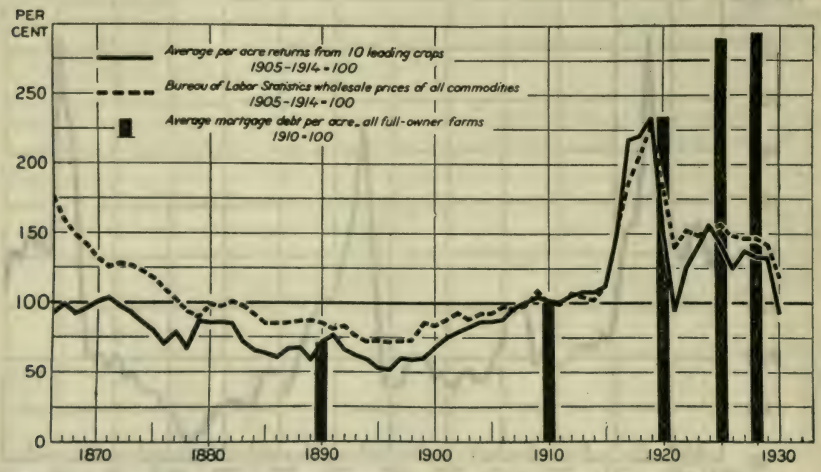

FIGURE 18.—RETURNS PER ACRE OF 10 LEADING CROPS, PRICE LEVEL, AND AVERAGE DEBT PER ACRE, 1866–1930

The value of returns from the 10 leading crops has shown a fairly close relation to the general price level from 1866 to 1930. The amount of indebtedness per acre of owner-operated farms also showed a close relation to the general price level from 1890 to 1920. Thereafter the debt increased while prices fell. The result was an increased burden with the means of carrying it reduced nearly one-half.

net income per acre from the land and how it will be influenced by changes in price level. It is assumed that the farmer's only means of caring for the debt is the annual net income from the land; this may be either the net cash rent or the net returns from crops over a period of several years. In either case the changes in the price level will affect in equal measure the income that is available for carrying indebtedness. But if the borrower has other resources, he may be able to retain his farm.

First, attention must be given to possible changes in the price level that may occur during the next 25 to 35 years. On the basis of 1913 prices as 100, the wholesale-price index in 1890 was at 80, in 1920 at 226, and in 1929 it had declined to 147. The land-value index, which was 100 in 1912–1914, had been about 90 in 1910. It rose to 170 in

[14] Corn, wheat, oats, barley, rye, buckwheat, potatoes, all hay, tobacco, and cotton, which comprise nearly 90 per cent of the area in all field crops, the average value of which closely approximates the value per acre of the aggregate of all crops.

1920 and declined to 116 in 1929. These occasional variations in price level, and hence in the debt-paying power of land income, suggest that mortgages incurred during high prices require the greatest caution. Although the interest on a loan as large as $60 per acre at 6 per cent may be met with a per-acre return of $6, the interest bill of $3.60 can not be met if the price level has fallen one-half so that the return from the land has a value of only $3. The sale price of the land may be greater or less than the amount of the loan, but the limiting factor for the farm owner is the current debt-paying power of the land return.

The selling price at the time the loan is made is not a safe guide as to ability to repay the loan many years later. Hence the farmer who wishes to keep his farm must consider its net annual income in relation to the loan. Incomes expressed in dollars also reflect the price level prevailing at the same time. It is, therefore, necessary to reduce incomes to a common basis by dividing them by a price index of purchasing power to get a figure that represents the net income of the land uninfluenced by price level. With the amount of the land return thus expressed in terms of purchasing power the amount of debt that the return will support may be found by dividing the return by the mortgage rate of interest. The result will be the maximum amount of money which will be possible of repayment with prices equal to, or above the price-index base, and provided that all the income is applied to carrying the indebtedness.

This problem may be illustrated first by use of assumed cash-rent returns for a period when the price level is steadily rising. Table 36, shows the value of given net rents or returns per acre at different stages of price level, and the corresponding amount of indebtedness that could be carried if all the rent were applied to that purpose. The capitalization rate used is 5.5 per cent. The amount of debt that could be carried will be greater or less than that indicated according as the interest rate is less or more than 5.5 per cent. This amount may be found for any rate by dividing the converted land return by the rate actually in effect.

TABLE 36.—*Amount of mortgage debt per acre at 5.5 per cent which may be carried by net land income per acre, at various price levels*

Income and supportable debt per acre when the price level is—											
100		60		80		120		140		200	
Income	Supportable debt	Income	Supportable debt	Income	Supportable debt	Income	Supportable debt	Income	Supportable debt	Income	Supportable debt
Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
3	55	1.80	33	2.40	44	3.60	65	4.20	76	6	110
4	73	2.40	44	3.20	58	4.80	87	5.60	102	8	146
5	91	3.00	55	4.00	73	6.00	109	7.00	127	10	182
6	109	3.60	65	4.80	87	7.20	131	8.40	153	12	218
7	127	4.20	76	5.60	102	8.40	153	9.80	178	14	254

The use of actual data as in Table 37 demonstrates further the allowances necessary in arriving at the debt-carrying capacity of a given farm under various changes in price level that may occur during

a period for which the average mortgaged farm is encumbered. In the case cited, a gross rent of $8.19 in 1920 was equivalent to a net of $6.24. The general price level was then at 226. With the price level of 200 the net rent would carry a debt of $100 at 5.5 per cent. With rent reflecting prices at the 1913 level, however, it would be sufficient to carry the interest on a debt of only $50 per acre.

TABLE 37.—*Debt-carrying capacity of land income in Iowa at various price levels for selected areas, stated years from 1900 to 1920*

Year	Gross rent per acre [1]	Net rent per acre [2]	Index of wholesale prices, 1913=100 [3]	Net rent corrected for price change, 1913=100	Amount of mortgage debt at 5.5 per cent which may be carried by net land income at price level of—			
					100 (1913)	80 (1900)	150 (1916–1925)	200 (1919)
	Dollars	*Dollars*	*Per cent*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
1900	3.29	2.87	80.5	3.56	65	52	98	130
1905	3.57	2.99	86.2	3.47	63	50	95	126
1910	4.22	3.51	100.9	3.48	63	50	95	126
1913	4.60	3.55	100.0	3.55	65	52	98	130
1920	8.19	6.24	226.2	2.76	50	40	75	100

[1] U. S. Dept. Agr. Bulletin 1224 (*6*).
[2] Gross rent less taxes and depreciation. Depreciation computed at 3 per cent of value of land and buildings. Taxes computed from State auditor's reports.
[3] Bureau of Labor Statistics (*22*).

Other price indexes may be used instead of the Bureau of Labor Statistics index used here, the farm-price index being the best for the years for which it is available. The general results are similar in showing the occasional wide variations in debt-carrying capacity caused by changes in price level.

CROP PAYMENTS AS MEANS OF AVOIDING DIFFICULTIES FROM PRICE-LEVEL CHANGES

The large proportion of the value of the land represented by the average mortgage given on land transfers in addition to the greater number of such sales, is thus seen as the potential cause of much ultimate difficulty. The normal course of the life of every rural community gives rise to a considerable annual sale and purchase of farms in which retirement of some farmers and the commencement of farming by others is a principal cause. The quickened activity of land sales during high prices makes it especially desirable that farmers beginning at that time shall not be so handicapped by fixed debt that they will subsequently fail or be compelled to farm at a loss.

One way of meeting this problem of retiring debt under falling prices is by providing that the mortgage shall be paid by means of a share of the annual crop from the land, or by the money equivalent of such share, rather than in term of dollars of changeable purchasing power. This is done by considering the farm as worth a given multiple of its own income.

The risk to the seller then becomes no greater than in the case of share renting for a period of years, and the buyer has an incentive to produce good crops since both receive a fixed share of the returns rather than a fixed amount. Payments for arable pasture and other tillable land not planted to money crops can be calculated on the

basis of the return from crop acres. Payments on nontillable land might be determined from a ratio of its acre returns to returns from crop acres. This method, occasionally used in western areas, could have prevented many foreclosures and much distress on land that burdened its owners in the decade following 1920. Such a plan is probably most practicable for transactions between individuals, the kind of dealings which predominate in periods of high prices.

Difficulties involved in such transfer procedure would require careful protection of the interests of buyer and seller. In general, these problems are of the same nature as the annual problems connected with share-rented farms. The requirement of some down payment and the designation of a trustee would increase the probability of faithful execution of contracts.

POLICY OF LENDING AGENCIES WITH REGARD TO LOAN RATIOS

Maintenance of a margin of approximately 50 per cent of the selling value of the land has been either from law or custom a more or less established feature with many farm-mortgage lenders for a considerable time. The Federal land banks and joint-stock land banks, from the beginning of the operation of the system, have been permitted to offer as security for bond issues only those mortgages that represent an amount not in excess of 50 per cent of the value of the land, and 20 per cent of the insured value of the improvements.

This policy, adhered to generally before the World War, has not been essentially altered since. A summary of the loan practice of principal investment concerns in leading agricultural States indicated that the maximum proportion of current market value that the owners of farm lands obtained by first mortgages thereon in 1929 averaged approximately 43 to 44 per cent (*3*). Of 38 life-insurance companies that loan on farms, 26 reported a loan limit at 50 per cent; 3, at 45 per cent; 4, at 40 per cent; and 4, at various ranges of 30 to 50 per cent; and only 1 at 50 to 60 per cent.

Although most agencies appear to be continuing the loan limit of 50 per cent on new loans, some modifications are occurring. In the Southwest, for example, some companies that formerly had a 40 per cent limit, more recently have been reported as loaning at 50 per cent. On the other hand, some companies that formerly included buildings in the appraised value have since applied the ratio to land only. More important in increasing the ratio of mortgage to value have been the liberal credit policies on sales of foreclosed land whereby, with only a small payment down, a mortgage is taken back for a large percentage of the sale price. Some of this modification of policy is due to a recognition of the arbitrary nature of a fixed 50 per cent loaning limit under all conditions of changing price levels.

The attitude of lenders toward the proportion of debt in land sales has a bearing on the outstanding volume of mortgage debt. Land sales made with small initial payments have the effect of raising the mortgage debt ratio to a high percentage of value of the particular farm. But where foreclosure has occurred on account of large mortgages, resale of the land may be made on terms that result in placing an equal amount of debt on the land. The fact that transferred farms in 1925 to 1928 had approximately the same ratio of debt before as after transfer suggests that no great change in debt is likely to occur as a result of sale of land during periods of low activity in sales.

RELATION OF LOAN RATIOS TO TERM OF LOANS

The question of maintaining the loaning ratio does not become a problem on loans outstanding unless the term expires and the mortgage becomes due. The regular payment of interest and required installments on principal generally suffices to keep the loan in good standing. If the term expires and renewal is desired, consideration must be given to the value of land at that time, in fixing the loaning rate. The Federal system and the principal State systems have not had to renew many loans, because of the long term generally used and the fact that payments in amount sufficient to retire the debt during this term are required by the loan contract.

RECENT CHANGES IN TERM AND PAYMENT METHODS

Insurance companies and other agencies whose loans usually run for periods of 5 to 10 years or less have been facing the problem of reloaning at higher ratios or of reducing the amount granted. Of 40 life-insurance companies reporting in 1929 on the term of their loans, 13 loaned only for periods of 5 years, 14 loaned for periods of 5 to 9 years, 3 for periods of 5 to 7 years, 2 for 7 years, 2 for 3 to 10 years, and 4 at varying terms of 1 to 20 years (*13*). It is evident that no material change has occurred during recent years in the length of term offered by these sources.

In contrast, the Federal and joint-stock land-bank loans are all of the amortization character. They typically run for 33 to 35 years, and only occasionally for shorter periods; small fractions of the principal are payable annually or semiannually, but none of the loans are due as a whole. Any changes in volume of outstanding mortgage credit from these sources, therefore, aside from those due to the amortization payments, foreclosures, or replacements by other mortgages must be confined to new loans.

Most loans of other agencies are also of short duration. The amount of amortization loans thus continues to be largely confined to the loans of the Federal system, plus the loans by the State systems. A few insurance companies offer loans on the amortization plan, but the total volume still appears to be relatively unimportant.

Since 1928 a more extended use has been made of the plan requiring one or more annual payments in gradual reduction of the principal. Payment under this plan, sometimes known as a "curtail," does not undertake complete amortization but only a reduction of the principal, often amounting to several hundred dollars per year. The Middle West and the Southwest have made the most extensive use of this modification of the straight-term loan.

CONCLUSIONS AND SUMMARY

Land and buildings form about three-fourths of the farmers' assets and a corresponding proportion of farm credit is represented by mortgages on real estate. Increases in farm-mortgage debt, accumulated during the period of active land sales at high prices ended in 1920, were continued in the following years by extensive funding of short-term credit into mortgages.

Increase of indebtedness while prices were declining has brought out numerous problems in farm-mortgage financing. The long-term nature of most land-secured debts which average 30 years or more

makes the usual arrangement for short term with frequent renewal a costly practice. Determination of a satisfactory basis for long-term loans in view of possible price changes probably has been the most serious question confronting the user of mortgage credit. Advantageous timing of farmers' borrowing with respect to money-market changes is necessary. These demands require that farmers be supplied with current information that will enable them to manage their credit effectively.

In general the problems in farm-mortgage financing consist of adapting financial facilities and practice to the effective establishment and operation of economic farm units. Whenever the security offered is adequate, there should be a dependable supply of credit available at a cost consistent with the risk involved. The term should be sufficiently long to accomplish the purpose of the loan or to allow convenient replacement and the method of payment should be that best adapted to the borrower's probable means. Agriculture has been slower in developing the means of achieving these ends than have some other lines of enterprise. Much of the improvement required awaits more attention by farmers.

Events since 1910 have not materially changed the geographical distribution of the country's volume of farm-mortgage credit. In 1928 over 60 per cent of farm-mortgage debt was in the North Central States and less than 20 per cent was in the Southern States.

Farmers who own the land they operate have a greater interest in farm-mortgage problems than do farmers of other tenures. Partly on account of larger aggregate acreage and partly because of greater dependence upon the land as a basis of loans, owner-operated farms in 1928 had nearly 59 per cent of all farm-mortgage debt, as compared with 38 per cent for tenant-operated farms and less than 3 per cent for manager farms. Tenant and manager farms being of larger average size have greater debt per farm. Despite these proportions, the debt on tenant farms tended to increase relatively more rapidly between 1925 and 1928 than debt on owner-operated land where heavier loans were an obstacle to further borrowing.

Despite the continued rise in the total amount of farm mortgages up to 1928, a movement toward reduction set in soon after 1920. Beginning in the Western States and gradually moving eastward, sharp declines in land values and in other prices were followed by fewer land sales, and smaller loans and renewals, while widespread foreclosure and repossession of title on defaulted contracts were strong forces working toward a lower outstanding debt.

The down turn in mortgage volume in 1928 brought to a close the long upward movement covering three decades. The long period of rising prices and increasing mortgage credit before 1920 was followed by eight years of further increase despite price declines. This period witnessed a notable accumulation of mortgages by insurance companies and the Federal and joint-stock land banks. Finally, after the break in prices, the debt held by commercial banks and individuals was transferred to other lenders as the movement entered upon its final phase—a reduction of the general volume of farm-mortgage debt of the country.

The relative importance of sources of farm-mortgage credit during the last decade has shown a decline in the part played by individuals and commercial banks, and a pronounced rise in the importance of

lending institutions specializing on long-term loans. In the course of eight years, 1920 to 1928, the proportion of all mortgage credit supplied by commercial banks declined from 18.4 to 10.8 per cent. Meanwhile the proportion held by life-insurance companies rose from 12.4 to 22.9 per cent, and the combined loans of the Federal and joint-stock land banks increased from 4.3 to 19.1 per cent. This shift has carried gains for the improvement of agricultural finance. Commercial banks have liberated a considerable amount for current loans, borrowers have been financed for longer terms and at lower rates, and much credit of a capital nature has been given a more appropriate basis in capital security.

Marked variation appears in the proportions of lenders' holdings among different regions. In the North Atlantic States and on the Pacific coast the greater part of farm-mortgage credit is provided by individuals and commercial banks. Insurance companies have concentrated their farm loans in the four geographic divisions centering on the Mississippi Valley where higher land values and heavier credit demands have permitted larger individual loans. The Federal and joint-stock land banks have distributed their loans widely but have made the heaviest advances in the South. Mortgage companies have centered their activity in the Western and Mountain divisions. Loans by individuals tend to approximate 30 per cent of the total in most divisions, save in the North Atlantic, where they assume a dominant proportion, and in the south central divisions, where they are but half the national average.

Since 1914 the outstanding sectional difference in demand for mortgage credit has been the continued demand for credit in the Western States. Other significant differences are reflected in the relative position of lenders. Mortgage credit from banks, though declining in the country as a whole, has had an increasing part in the northeast and Pacific regions. Meanwhile, insurance loans have declined in the North Atlantic States while steady expansion has occurred in the Middle West. The new facilities provided by the Federal farm loan system have spread over a wide area but have tended to serve less favorable territory, with especial expansion in the South.

Changes in the trend of total volume of mortgage credit extended by principal institutions appear to have been preceded one or two years by changes in volume of loans by life-insurance companies. The comparatively short term of loans from these sources brings a substantial proportion of the total to maturity and redistribution each year, thus making them early indicators of mortgage movements.

Individual mortgage loans on owner farms average nearly $4,000. Among lending agencies insurance-company loans are largest, the average reported being over $10,000. The average loan held by joint-stock land banks was next in size, about $8,000. Loans by Federal land banks average approximately one-half the size of those from the joint-stock land banks. Restrictions of the Federal land banks to loans on owner-operated farms keeps these lenders from participating in the financing of tenant-operated and manager-operated farms which average larger in size and require larger loans. Among mortgages held by individuals, active farmers have the smallest amount and the smallest average size of loans, representing approximately one-third the size of insurance loans. Loans are largest in the North Central States mainly as a result of higher land values in that region. Partly

for this reason insurance companies have concentrated their farm-mortgage business in those States.

The percentage of mortgaged owner-farms increased steadily from less than 28 in 1890 to more than 37 in 1920. Extensive foreclosures and repossession of titles following 1920 probably contributed to the lower percentage of mortgaged farms reported by the census of 1925. Farmers' reports received since that census, indicate a continuation of the increase in the number of farms having mortgage incumbrance.

Farms operated by their owners more generally have mortgages than do other farms, save part-owner farms which have such debt in 48 per cent of cases as compared with 34 per cent for full-owner farms. Greater capital requirements in proportion to the land owned account for most of these relatively higher debt frequencies.

Comparison of debt frequency on tenant-operated farms owned by farmers and those owned by others indicates that farmers are much more often in debt for such land and for larger proportions of value, than are nonfarmers. A greater tendency to acquire additional land and a relative lack of funds among farmers probably account for this unfavorable comparison.

Most of the increase in the number of mortgaged farms between 1925 and 1928 occurred on farms owned by the same persons at both dates. Farms that were transferred during that period had mortgage debt in nearly three-fourths of all cases before transfer, and the net increase in debt frequency incident to change of ownership was negligible. These facts suggest that, in addition to transfers necessitated by debt distress, voluntary transfers may be facilitated by the existence of a mortgage on the land because of the smaller consideration represented by the equity.

The ratio of mortgage debt to the value of farms has tended to rise since 1910. High land prices and increased land transfers during the years prior to 1921 more than doubled the 1920 debt above the debt of 1910. The further increase from refunding operations after 1920 and the great decline in land prices left a debt in 1928 equal to 21 per cent of the value of all farms as compared with a debt ratio of only 9.5 in 1910. The smallest change in debt ratios among geographic divisions was the narrow variation within a range of 10 and 14, in the North Atlantic States, where both land values and debt had been least affected by events from 1915 to 1920. The greatest change appeared in the Mountain States where expanding developments before 1920 and sharp recession afterward brought the debt ratio from 8.6 in 1910 to 24.2 of the value of all farms in 1928.

When confined to mortgaged farms the increase in the ratio of debt to value since 1910 was only slightly less marked, having risen from 27.3 in 1910 to 46 in 1928 for full owner-operated farms as a whole. The lower debt ratios and larger equities on tenant-operated farms in 1925 partly accounts for the greater increase in debt per farm which such farms reported in 1928.

Among tenant-operated farms notably greater indebtedness was found on those owned by farmers operating other farms. The fact that such farms are mortgaged in more instances and for larger proportions of value indicates that farmers have been more willing to incur indebtedness in purchasing land than have others. In the aggregate active farmers have approximately three-fourths of the debt on farm real estate.

A distribution of individual mortgaged farms on the basis of ratios of debt to value in 1928 showed a concentration of more than 60 per cent of loans with debt ranging from 15 to 55 per cent of the farm value. More than 35 per cent of the mortgaged farms were reported by their owners as having debt amounting to more than half of the farm value, 12 per cent were more than three-fourths of the value, and more than 4 per cent were greater than the farm value. In the North Central and South Atlantic divisions the loans in excess of farm value ranged from 6 to 7 per cent.

A relatively close correspondence appears between the percentage of farms with debt in excess of value and the percentage of farms foreclosed during the same year. In most divisions, foreclosure appears to have taken place somewhat before the debt and the farm value reached equal amounts. In the higher-priced land of the North Central States, the reverse seems to have been true. Allowance for unpaid interest, taxes, costs, and delay of foreclosure have operated to hasten the taking of title, whereas reluctance to assume operating responsibilities and hope of gradual debt liquidation have tended to leave farms in the hands of their owners.

Great differences appear in the proportions of debt on newly mortgaged farms and on the mortgaged farms that are transferred. Farms not previously encumbered reported mortgages averaging only 30 per cent of their value as contrasted with debt ratios of 59 to 65 per cent on farms that had transferred title during the same period. The smaller equities of encumbered lands result in smaller consideration requirements which facilitate sale or trade.

Additional significance in the proportion of farm-mortgage debt to the value of farms appears in the fact that the average interest rate borne is commonly higher than the average rate of return received. Although such debt in 1925 was less than one-fifth of all land value, the interest payments approximated one-third of all land returns computed on the basis of net rent.

Interest rates on farm mortgages reported in 1928 averaged somewhat lower than those given in the 1920 census. The lowest average was 5.5 per cent in the West North Central division, and the Mountain division was highest with 6.7 per cent. A similar range appeared among the rates of various lending agencies, Federal land banks and insurance companies averaging 5.5 per cent while commercial banks averaged 6.7 per cent. These relative rate positions of different lenders tend to appear throughout the various divisions. The fact that the great majority of loans have been made at even percentage rates has practical significance in indicating the probable course of the mortgage-loan market.

Changes in interest rates quoted on farm mortgages appear to lag six months or a year behind changes in short-term rates and bond yields, both on rises and declines. Farmers having such financing in prospect should watch the course of the short-term money markets for indications of the probable course of rates on new farm mortgages.

Occasional marked rises in money rates on the central markets present periodic problems in supply and cost of farm-mortgage credit. Legal limitations on the rates chargeable on the Federal and joint-stock land banks have prevented their entering the market at such times, and more profitable uses for funds have drawn off other capital.

In so far as the farmer relies upon local sources of funds for mortgage credit there is likely to be a need for mortgage financing at times when conditions are least favorable, when refunding must be done to take care of short-term debt, and when interest rates and terms prevent advantageous arrangements. Because of this set of conditions the heaviest amounts of borrowing occur at periods of highest rates. Inasmuch as the farmer's alternatives of financing are limited, he should watch the money markets carefully for indications that may have significance to him.

The importance that mortgage credit holds in the farm business warrants more care in its management than is often given it. This applies both to questions of favorable rates and other terms and to problems likely to arise during the course of many years. Renewal rather than repayment is the dominant practice in farm-mortgage finance. Within the period of 25 to 35 years that the average mortgaged farm remains mortgaged the farmer with the commonest form of mortgage must face the problems of refinancing from five to seven times. Experience has indicated, moreover, that total annual increments in the farmer's wealth have been much below the amount necessary to retire the average mortgage in the average term of years. Since the average term of debt is approximately the same as the term of loans which may be amortized by an annual payment of 1 per cent of the principal, that is, 30 to 35 years, most farmers would do well to consider this type of loan when arranging initial farm financing.

Under present conditions a farmer's principal mortgage problems grow out of the recurrent necessity of readjusting old debt. He encounters competition with new financing in other lines and in greater amount. A farmer frequently has a heavy loan already on the farm, so that a first-mortgage loan can not be favorably obtained to cover the debt.

No problem in farm-mortgage finance is more serious than that of changes in price level. Since 1920 great numbers of farmers have lost property because obligations incurred at high prices have had to be repaid with dollars of much greater purchasing power than in war time. Failure to recognize the temporary character of the prices prevailing for land and products at that time has been a leading cause of financial difficulty since. In general, lending agencies tended to make loans proportionate to land value then current; as a result they have since acquired much land that they have not wanted, and farmers have sustained heavy losses in equities.

Three times since 1800 prices have risen to extreme heights for a short term of years and have declined to near former levels. Each of these instances has been followed by general business distress, indicated by bank failures, bankrupticies, and foreclosures. The long term of farm debt requires that the farmer have in mind such possibilities when contracting farm-mortgage encumbrance. Some protection is afforded by the loan limitations imposed by most lenders on first mortgages. In the case of land-purchase mortgages, however, the buyer must exercise his own discretion. The maximum amount of debt that can be incurred with safety can be computed approximately from net returns with allowance for existing price levels and potential changes. A system of crop payments for land purchased

in periods of high prices could obviate much difficulty growing out of such periods.

The policy of lending agencies in maintaining loan limits of approximately 50 per cent of the value of land has not changed substantially from pre-war years. As long as this policy is followed arbitrarily, it will continue to be inadequate protection against severe price recessions. The continued nature of farm-mortgage debt requires that farmers guard against such dangers by limiting their borrowings in periods of high prices and not be guided by the amount lenders are willing to advance.

APPENDIX

TABLE 38.—*Number and amount of farm loans closed and outstanding, made by the Jewish Agricultural Society (Inc.), by years, 1900–1930*

Year	Loans closed				Loans outstanding	
	Number	Amount		Index of average amount 1921–22=100	Number	Amount
		Total	Average			
		Dollars	*Dollars*	*Per cent*		*Dollars*
1900	25	9,125	365	49	23	7,503
1901	65	29,015	446	60	87	36,821
1902	65	33,407	514	70	150	67,508
1903	106	44,006	415	56	224	99,161
1904	125	52,150	417	56	316	130,969
1905	134	56,547	422	57	386	162,960
1906	151	63,836	423	57	481	208,099
1907	204	114,812	563	76	578	282,494
1908	263	160,039	609	82	710	399,194
1909	239	129,443	542	73	816	478,655
1910	281	178,562	635	86	983	571,103
1911	320	237,576	742	100	1,069	686,657
1912	356	222,433	625	85	1,186	797,503
1913	358	203,991	570	77	1,342	902,649
1914	331	186,734	564	76	1,480	978,197
1915	358	162,897	455	62	1,628	980,830
1916	320	182,599	571	77	1,713	977,424
1917	387	211,268	546	74	1,761	995,085
1918	315	177,848	565	76	1,641	942,268
1919	364	254,376	699	95	1,503	933,564
1920	403	369,070	916	124	1,468	1,064,179
1921	407	312,772	768	104	1,470	1,144,159
1922	448	318,176	710	96	1,512	1,228,818
1923	318	231,145	727	98	1,457	1,192,017
1924	401	249,983	623	84	1,440	1,190,234
1925	436	269,662	618	84	1,418	1,190,087
1926	431	272,416	632	86	1,409	1,206,694
1927	532	344,369	647	88	1,465	1,299,426
1928	441	271,730	616	83	1,467	1,340,476
1929	417	249,808	599	81	1,471	1,346,027
1930	463	222,501	481	----------	1,520	1,377,750

TABLE 39.—*Estimated total farm-mortgage debt: 1920*

State and geographic division	Estimated total farm-mortgage debt, 1920	Estimated debt of—		
		Owners [1]	Managers	Tenants
	Dollars	*Dollars*	*Dollars*	*Dollars*
Maine	20,890,000	19,650,000	920,000	320,000
New Hampshire	8,600,000	7,470,000	930,000	200,000
Vermont	29,040,000	25,330,000	1,920,000	1,790,000
Massachusetts	34,180,000	26,070,000	7,300,000	810,000
Rhode Island	2,350,000	1,750,000	450,000	150,000
Connecticut	25,800,000	20,420,000	4,530,000	850,000
New England	120,860,000	100,690,000	16,050,000	4,120,000
New York	224,060,000	167,850,000	21,810,000	34,400,000
New Jersey	39,500,000	27,910,000	5,090,000	6,500,000
Pennsylvania	133,080,000	97,140,000	11,480,000	24,460,000
Middle Atlantic	396,640,000	292,900,000	38,380,000	65,360,000
Ohio	210,760,000	148,490,000	8,260,000	54,010,000
Indiana	206,600,000	142,240,000	6,180,000	58,180,000
Illinois	502,850,000	291,080,000	17,550,000	194,220,000
Michigan	215,740,000	176,000,000	8,360,000	31,380,000
Wisconsin	455,470,000	389,560,000	12,590,000	53,320,000
East North Central	1,591,420,000	1,147,370,000	52,940,000	391,110,000
Minnesota	455,540,000	323,870,000	7,420,000	124,250,000
Iowa	1,098,970,000	639,440,000	20,070,000	439,460,000
Missouri	385,790,000	280,210,000	10,020,000	95,560,000
North Dakota	267,780,000	198,620,000	6,700,000	62,460,000
South Dakota	278,880,000	183,420,000	4,760,000	90,700,000
Nebraska	416,860,000	253,820,000	8,090,000	154,950,000
Kansas	295,870,000	187,990,000	6,300,000	101,580,000
West North Central	3,199,690,000	2,067,370,000	63,360,000	1,068,960,000
Delaware	8,990,000	4,720,000	500,000	3,770,000
Maryland	49,230,000	30,250,000	4,730,000	14,250,000
District of Columbia	340,000	110,000	150,000	80,000
Virginia	61,600,000	46,910,000	3,940,000	10,750,000
West Virginia	15,960,000	12,940,000	930,000	2,090,000
North Carolina	56,580,000	36,550,000	1,350,000	18,680,000
South Carolina	51,220,000	28,370,000	1,380,000	21,470,000
Georgia	83,840,000	41,700,000	3,940,000	38,200,000
Florida	19,710,000	14,210,000	3,950,000	1,550,000
South Atlantic	347,470,000	215,760,000	20,870,000	110,840,000
Kentucky	104,100,000	76,610,000	2,260,000	25,230,000
Tennessee	83,130,000	56,980,000	1,450,000	24,700,000
Alabama	55,450,000	32,500,000	1,590,000	21,360,000
Mississippi	77,420,000	33,290,000	3,540,000	40,590,000
East South Central	320,100,000	199,380,000	8,840,000	111,880,000
Arkansas	76,870,000	45,040,000	2,800,000	29,030,000
Louisiana	41,250,000	24,170,000	4,050,000	13,030,000
Oklahoma	188,890,000	112,300,000	4,000,000	72,590,000
Texas	396,670,000	226,450,000	23,960,000	146,260,000
West South Central	703,680,000	407,960,000	34,810,000	260,910,000
Montana	154,940,000	127,260,000	10,240,000	17,440,000
Idaho	115,350,000	89,220,000	5,940,000	20,190,000
Wyoming	32,970,000	24,920,000	4,360,000	3,690,000
Colorado	138,400,000	97,610,000	6,990,000	33,800,000
New Mexico	23,670,000	18,280,000	2,560,000	2,830,000
Arizona	31,790,000	20,060,000	5,850,000	5,880,000
Utah	35,550,000	30,620,000	1,440,000	3,490,000
Nevada	11,880,000	7,950,000	3,050,000	880,000
Mountain	544,550,000	415,920,000	40,430,000	88,200,000
Washington	116,740,000	92,070,000	6,800,000	17,870,000
Oregon	91,090,000	73,810,000	5,620,000	11,660,000
California	425,460,000	300,920,000	69,970,000	54,570,000
Pacific	633,290,000	466,800,000	82,390,000	84,100,000
United States	7,857,700,000	5,314,150,000	358,070,000	2,185,480,000

[1] The mortgage debt on fully owned farms, as shown by the census, amounted to 13.3 per cent of the value of all fully owned farms (including those not mortgaged). This ratio (or the corresponding ratio for each State) was used in estimating the debt on farms operated by part owners and managers. The mortgage debt on tenant farms, according to special reports received from the owners of such farms in selected counties, was 9.2 per cent of the value of all tenant farms covered by these reports.

TABLE 40.—*Farm-mortgage debt in the United States according to tenure of farms, by States and geographic divisions, January 1, 1910*

State and geographic division	Estimated total farm-mortgage debt Jan. 1, 1910	Estimated farm mortgage debt of—		
		Owners [1]	Tenants	Managers
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
Maine	13,210	12,480	270	460
New Hampshire	5,870	5,210	180	480
Vermont	15,850	13,360	1,260	1,230
Massachusetts	22,890	17,560	740	4,590
Rhode Island	2,210	1,570	180	460
Connecticut	16,080	12,980	660	2,440
New England	76,110	63,160	3,290	9,660
New York	154,190	110,540	30,800	12,850
New Jersey	31,720	21,300	5,940	4,480
Pennsylvania	95,620	67,780	21,270	6,570
Middle Atlantic	281,530	199,620	58,010	23,900
Ohio	113,320	79,440	30,100	3,780
Indiana	111,280	77,780	30,340	3,160
Illinois	266,780	156,010	104,510	6,260
Michigan	109,970	89,850	17,030	3,090
Wisconsin	193,600	160,380	28,960	4,260
East North Central	794,950	563,460	210,940	20,550
Minnesota	146,160	105,990	37,680	2,490
Iowa	431,500	263,980	161,070	6,450
Missouri	202,650	147,640	49,950	5,060
North Dakota	101,450	77,110	22,250	2,090
South Dakota	88,700	58,600	28,810	1,290
Nebraska	161,850	90,830	68,320	2,700
Kansas	163,770	106,510	53,900	3,360
West North Central	1,296,080	850,660	421,980	23,440
Delaware	6,500	3,320	2,960	220
Maryland	29,580	17,150	9,170	3,260
District of Columbia	290	60	140	90
Virginia	24,000	17,680	5,090	1,230
West Virginia	8,210	6,440	1,480	290
North Carolina	18,960	12,210	6,190	560
South Carolina	20,530	12,250	7,540	740
Georgia	28,800	13,300	14,520	980
Florida	4,380	3,120	680	580
South Atlantic	141,250	85,530	47,770	7,950
Kentucky	40,510	27,960	11,530	1,020
Tennessee	26,850	15,790	10,540	520
Alabama	24,880	13,220	11,110	550
Mississippi	31,320	16,050	14,070	1,200
East South Central	123,560	73,020	47,250	3,290
Arkansas	22,200	10,970	10,580	650
Louisiana	19,090	10,920	5,690	2,480
Oklahoma	77,680	38,360	38,440	880
Texas	172,240	95,370	61,960	14,910
West South Central	291,210	155,620	116,670	18,920
Montana	19,620	12,710	5,060	1,850
Idaho	24,270	16,940	6,090	1,240
Wyoming	7,820	5,250	1,160	1,410
Colorado	41,800	23,450	15,590	2,760
New Mexico	4,810	3,010	990	810
Arizona	4,880	2,980	1,360	540
Utah	7,170	5,570	1,220	380
Nevada	3,340	1,640	620	1,080
Mountain	113,710	71,550	32,090	10,070
Washington	45,040	34,740	7,820	2,480
Oregon	34,950	25,930	6,630	2,390
California	122,080	74,510	25,280	22,290
Pacific	202,070	135,180	39,730	27,160
United States	3,320,470	2,197,800	977,730	144,940

[1] Includes all part-owner farms.

TABLE 41.—*Farm mortgages outstanding in 13 Iowa townships, classified according to lenders, December 31, 1915–1925* [1]

Year	Former owners	Private investors	Insurance companies	Banks	Farm-mortgage companies	Land banks	Miscellaneous	Total
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
1915	1,503	1,809	1,390	1,254	160	----------	61	6,177
1916	1,568	1,998	1,754	1,297	171	----------	74	6,862
1917	1,657	2,205	2,151	1,494	206	----------	89	7,802
1918	2,254	2,269	2,278	1,485	211	95	98	8,690
1919	2,996	2,324	2,380	1,402	228	233	104	9,667
1920	5,249	3,025	2,702	1,851	312	273	130	13,542
1921	5,130	3,285	3,099	2,239	308	283	148	14,542
1922	4,670	3,276	3,360	2,176	293	558	121	14,454
1923	4,026	3,190	3,947	2,311	359	702	120	14,655
1924	3,509	3,146	4,261	2,358	404	760	106	14,544
1925	2,870	3,047	4,389	2,154	409	910	105	13,884

[1] Iowa State College Econ. Series Rept. No. 6 (*13*).

TABLE 42.—*Discount rates of the Federal Reserve Bank of New York, 1917–1931* [1]

Year	January	February	March	April	May	June	July	August	September	October	November	December
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1917	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.50
1918	4.50	4.50	4.50	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75
1919	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75
1920	6.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
1921	7.00	7.00	7.00	7.00	6.50	6.00	5.50	5.50	5.00	5.00	4.50	4.50
1922	4.50	4.50	4.50	4.50	4.50	4.00	4.00	4.00	4.00	4.00	4.00	4.00
1923	4.00	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
1924	4.50	4.50	4.50	4.50	4.00	3.50	3.50	3.00	3.00	3.00	3.00	3.00
1925	3.00	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
1926	4.00	4.00	4.00	3.50	3.50	3.50	3.50	4.00	4.00	4.00	4.00	4.00
1927	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.50	3.50	3.50	3.50	3.50
1928	3.50	4.00	4.00	4.00	4.50	4.50	5.00	5.00	5.00	5.00	5.00	5.00
1929	5.00	5.00	5.00	5.00	5.00	5.00	5.00	6.00	6.00	6.00	5.00	4.50
1930	4.50	4.00	3.50	3.50	3.00	2.50	2.50	2.50	2.50	2.50	2.50	2.00
1931	2.00	2.00	2.00	2.00	1.50	-------	-------	-------	-------	-------	-------	-------

[1] Compiled from Federal Reserve Board report (*26*).

TABLE 43.—*Average rates on prime commercial paper in New York, 1917–1931* [1]

Year	January	February	March	April	May	June	July	August	September	October	November	December
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1917	3.55	4.09	4.13	4.28	4.83	5.00	4.68	4.81	5.19	5.38	5.44	5.50
1918	5.58	5.69	5.88	5.90	5.88	5.88	5.88	5.94	6.00	6.00	5.97	5.78
1919	5.19	5.19	5.38	5.38	5.38	5.53	5.42	5.38	5.38	5.38	5.50	5.88
1920	6.00	6.50	6.75	7.00	7.50	7.75	8.00	8.00	8.00	8.00	8.00	8.00
1921	7.75	7.75	7.75	7.50	7.00	6.50	6.25	6.25	6.00	5.75	5.25	5.00
1922	4.75	5.00	4.75	4.50	4.25	4.25	4.00	4.00	4.25	4.50	4.75	4.75
1923	4.50	4.75	5.00	5.12	5.00	5.00	5.00	5.25	5.38	5.25	5.00	4.88
1924	4.75	4.75	4.62	4.50	4.38	3.62	3.38	3.12	3.25	3.12	3.37	3.62
1925	3.50	3.75	4.00	4.00	3.88	3.88	3.88	4.12	4.25	4.38	4.38	4.38
1926	4.38	4.25	4.38	4.38	4.00	4.00	4.12	4.38	4.62	4.62	4.50	4.50
1927	4.25	4.12	4.12	4.12	4.12	4.25	4.25	4.00	4.00	4.00	4.00	4.00
1928	4.00	4.00	4.12	4.37	4.50	4.88	5.12	5.37	5.63	5.50	5.38	5.38
1929	5.37	5.50	5.88	6.00	6.00	6.00	6.00	6.12	6.25	6.25	5.75	5.00
1930	4.88	4.75	4.25	3.88	3.75	3.50	3.25	3.00	3.00	3.00	2.88	2.88
1931	2.88	2.63	2.50	2.38	-------	-------	-------	-------	-------	-------	-------	-------

[1] Data for 1917 to 1919 from Harvard Review of Economic Statistics; data for 1920 to 1931 from Federal Reserve Board report (*26*).

TABLE 44.—*Farm mortgage loans reported by life insurance companies, in the United States, by geographic divisions, 1914–1930* [1]

Year	Reporting companies	Assets of reporting companies in percentage of admitted assets of all legal reserve companies	Farm-mortgage loans of reporting companies in—			
			United States	New England States	Middle Atlantic States	East North Central States
	Number	*Per cent*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
1914	126	96.95	646,962	105	359	116,801
1916	52	96.59	828,471	76	472	136,433
1917	150	96.98	923,040	34	378	143,229
1918	150	94.08	954,071	32	298	143,268
1919	39	88.40	858,313	30	121	128,465
1920	47	90.36	1,085,199	27	120	152,613
1921	52	94.50	1,306,251	29	436	181,367
1922	52	93.80	1,453,902	62	472	208,274
1923	52	93.13	1,662,375	53	803	250,559
1924	52	93.10	1,801,378	52	474	288,597
1925	52	92.90	1,878,643	42	434	315,033
1926	52	91.80	1,941,756	42	378	336,889
1927	52	91.60	1,982,412	39	329	347,011
1928	52	92.00	1,960,022	38	268	347,792
1929	52	91.90	1,930,373	33	246	349,205
1930	52	91.80	1,886,000			

Year	Farm-mortgage loans of reporting companies in—					
	West North Central States	South Atlantic States	East South Central States	West South Central States	Mountain States	Pacific States
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
1914	399,779	20,901	19,491	65,530	11,760	12,236
1916	508,177	30,902	30,742	87,152	16,089	18,428
1917	585,025	30,293	35,186	95,924	15,081	17,890
1918	593,882	30,364	38,829	108,868	18,879	19,651
1919	547,004	34,678	34,575	85,366	11,974	16,100
1920	684,139	46,088	48,537	118,481	17,177	18,018
1921	803,655	61,773	63,494	154,072	19,745	21,680
1922	881,745	66,511	71,374	173,981	23,453	28,030
1923	1,015,917	67,366	83,323	186,397	25,575	32,382
1924	1,098,573	66,196	91,534	191,921	26,366	37,665
1925	1,143,920	62,267	95,315	195,468	25,042	41,122
1926	1,176,009	60,348	98,163	201,210	24,263	44,454
1927	1,200,483	56,496	97,896	206,223	25,294	48,641
1928	1,181,488	54,134	95,504	205,011	25,632	50,155
1929	1,159,400	52,089	92,189	200,239	25,368	51,525
1930						

[1] From annual reports of the Association of Life Insurance Presidents (*5*).

TABLE 45.—*Average number of acres in farms, by tenure and geographic divisions* [1]

Geographic division and tenure	Average area per farm	Geographic division and tenure	Average area per farm
New England:	*Acres*	East South Central:	*Acres*
Full-owners	96	Full-owners	101
Tenants	105	Tenants	41
Part-owners	134	Part-owners	79
Managers	236	Managers	533
Middle Atlantic:		West South Central:	
Full-owners	82	Full-owners	199
Tenants	107	Tenants	92
Part-owners	133	Part-owners	440
Managers	204	Managers	3,923
East North Central:		Mountain:	
Full-owners	91	Full-owners	299
Tenants	130	Tenants	369
Part-owners	140	Part-owners	1,360
Managers	250	Managers	5,829
West North Central:		Pacific:	
Full-owners	172	Full-owners	116
Tenants	211	Tenants	259
Part-owners	381	Part-owners	694
Managers	628	Managers	724
South Atlantic:		United States:	
Full-owners	98	Full-owners	127
Tenants	54	Tenants	108
Part-owners	75	Part-owners	355
Managers	572	Managers	1,059

[1] Computed from 1925 census (*20*).

The value of farm implements sold by manufacturers in the United States, 1899 to 1928, was as follows:

	Million dollars		Million dollars
1899	85	1923	312
1904	89	1924	278
1909	121	1925	341
1914	132	1926	365
1920	471	1927	392
1921	([15])	1928	399
1922	223		

[15] No record.

LITERATURE CITED

(1) Anonymous.
1920–29. Com. and Financ. Chron. v. 110, 112, 114, 116, 118, 120, 122, 124, 126, 128, 130. [January issues in each volume.]

(2) ———
1928–30. INVESTMENTS OF TWENTY-FIVE LIFE INSURANCE COMPANIES. N. Y. Evening Post. [Issues for Monday editions for June 1928, 1929, and 1930.]

(3) ———
1929. TERMS ON WHICH INSURANCE COMPANIES LOAN ON FARM LANDS. Natl. Real Estate Jour. May 13, 1929, Table, p. 38.

(4) ———
1930. FARM LOANS TO BE INVESTIGATED. Natl. Underwriter 35(5): [3], 7.

(5) ASSOCIATION OF LIFE INSURANCE PRESIDENTS.
1914–30. PROCEEDINGS OF THE ANNUAL MEETINGS... 1914–1930.

(6) CHAMBERS, C. R.
1924. RELATION OF LAND VALUE AND LAND INCOME. U. S. Dept. Agr. Bul. 1224, 132 p., illus.

(7) CHILDS, C. F., and COMPANY.
1931. Investment Bulletin for July, 1931, 4 p., illus.

(8) FEDERAL LAND BANK OF WICHITA.
1930. THE REFINANCING OF FARMING IS EXPENSIVE. Financing of Farming v. 4, no. 9, 4 p.

(9) GOLDENWEISER, E. A., and TRUESDELL, L. E.
1924. FARM TENANCY IN THE UNITED STATES. AN ANALYSIS OF THE RESULTS OF THE 1920 CENSUS RELATIVE TO FARMS CLASSIFIED BY TENURE SUPPLEMENTED BY PERTINENT DATA FROM OTHER SOURCES. U. S. Dept. Com., Bur. of the Census, Census Monograph 4, 247 p., illus.

(10) GRAY, L. C., and LLOYD, O. G.
1926. FARM LAND VALUES IN IOWA. U. S. Dept. Agr. Bul. 874, 45 p., illus.
(11) LLOYD, O. G.
1919. STUDIES OF LAND VALUES IN IOWA. Iowa Agr. 20: 361–363.
(12) MELLON, A. W. [and others].
1930. ANNUAL REPORT OF THE SECRETARY OF THE TREASURY ON THE STATE OF FINANCES FOR THE FISCAL YEAR ENDED JUNE 30, 1929, with appendices. U. S. Treasury Dept. Doc. 3010, 968 p., illus.
(13) MURRAY, W. G., and GARLOCK, F. L.
1927. FARM MORTGAGE DEBT IN IOWA. Iowa Agr. Expt. Sta., Agr. Econ. Sec. Current Econ. Ser. Rpt. 6, 15 p.
(14) NATIONAL AUTOMOBILE CHAMBER OF COMMERCE.
1930. FACTS AND FIGURES OF THE AUTOMOBILE INDUSTRY. 1931 ed. (figures for calendar year 1930), 96 p., illus.
(15) OLSEN, N. A., BRANNEN, C. O., CADISCH, G. F., and NEWTON, R. W.
1925. FARM CREDIT, FARM INSURANCE, AND FARM TAXATION. U. S. Dept. Agr. Yearbook 1924: 185–284, illus.
(16) THOMPSON, C. W.
1916. COSTS AND SOURCES OF FARM-MORTGAGE LOANS IN THE UNITED STATES. U. S. Dept. Agr. Bul. 384, 16 p., illus.
(17) UNITED STATES DEPARTMENT OF AGRICULTURE.
1929. LIVESTOCK—MEATS—WOOL. U. S. Dept. Agr. Crops and Markets 6: 248–256.
(18) ——— BUREAU OF AGRICULTURAL ECONOMICS.
1930. GENERAL TREND OF PRICES AND WAGES. U. S. Dept. Agr., Bur. Agr. Econ. Agr. Situation 14 (1): 4.
(19) UNITED STATES DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS.
1922. FOURTEENTH CENSUS OF THE UNITED STATES TAKEN IN THE YEAR 1920. v. 6, Agriculture.
(20) ———
1927. UNITED STATES CENSUS OF AGRICULTURE, 1925. 3 v., illus. Washington, D. C.
(21) ———
1930. TREND OF BUSINESS MOVEMENTS. U. S. Bur. of the Census, Survey of Current Business 101: 23–48.
(22) UNITED STATES DEPARTMENT OF LABOR, BUREAU OF LABOR STATISTICS.
1928. INDEX NUMBERS OF WHOLESALE PRICES ON PRE-WAR BASE. 1890 to 1927... 50 p.
(23) UNITED STATES TREASURY DEPARTMENT, COMPTROLLER OF THE CURRENCY.
1921–31. REPORT OF THE COMPTROLLER OF THE CURRENCY. U. S. Treasury Dept. Annual Report of the Secretary of the Treasury on the State of the Finances... 1920–30.
(24) ——— FEDERAL FARM LOAN BOARD.
1916. FEDERAL FARM LOAN ACT. Rulings and Regulations of the Federal Farm Loan Board Sect. 45.
(25) ——— FEDERAL FARM LOAN BOARD.
1918–31. ANNUAL REPORTS OF THE FEDERAL FARM LOAN BOARD. 1–14 illus.
(26) UNITED STATES FEDERAL RESERVE BOARD.
1929–31. ANNUAL REPORTS OF THE FEDERAL RESERVE BOARD... Rpt. 15 (for year 1928), 331 p., illus., 1929; Rpt. 17 (for year 1930), 372 p., illus. 1931.
(27) VALGREN, V. N., and ENGELBERT, E. E.
1921. FARM MORTGAGE LOANS BY BANKS, INSURANCE COMPANIES, AND OTHER AGENCIES. U. S. Dept. Agr. Bul. 1047, 23 p., illus.
(28) ——— and ENGELBERT, E. E.
1922. BANK LOANS TO FARMERS ON PERSONAL AND COLLATERAL SECURITY. U. S. Dept. Agr. Bul. 1048, 26 p., illus.
(29) WIECKING, E. H.
1928. THE FARM REAL ESTATE SITUATION. 1927–28. U. S. Dept. Agr. Circ. 60, 64 p., illus.
(30) ———
1929. THE FARM REAL ESTATE SITUATION, 1928–29. U. S. Dept. Agr. Circ. 101, 67 p., illus.

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TECHNICAL BULLETIN NO. 287 FEBRUARY, 1932

FARM-MANAGEMENT PROBLEMS IN SHIFTING FROM SACK TO BULK HANDLING OF GRAIN IN THE PACIFIC NORTHWEST

BY

NEIL W. JOHNSON
Associate Agricultural Economist
Division of Farm Management and Costs
Bureau of Agricultural Economics

E. F. LANDERHOLM
Assistant in Farm Management
Washington Agricultural Experiment Station

G. W. KUHLMAN
Assistant Economist in Farm Management
Oregon Agricultural Experiment Station

and

T. L. GASTON
Associate Agricultural Economist
Idaho Agricultural Experiment Station

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IN COOPERATION WITH THE AGRICULTURAL EXPERIMENT STATIONS
OF WASHINGTON, OREGON, AND IDAHO

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By NEIL W. JOHNSON, *Associate Agricultural Economist, Division of Farm Management and Costs, Bureau of Agricultural Economics, United States Department of Agriculture;* E. F. LANDERHOLM, *Assistant in Farm Management, Washington Agricultural Experiment Station,*[1] G. W. KUHLMAN, *Assistant Economist in Farm Management, Oregon Agricultural Experiment Station; and* T. L. GASTON, *Associate Agricultural Economist, Idaho Agricultural Experiment Station*

In Cooperation with the Agricultural Experiment Stations of Washington, Oregon, and Idaho

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INTRODUCTION

Most of the grain produced on farms in Washington, Oregon, and Idaho has moved to market in burlap sacks. In the early days ship masters refused to carry bulk grain because of the hazard involved should the cargo shift in the rough voyage "around the Horn." Spoilage of bulk grain was experienced from extreme temperature changes encountered in the long journey. It was difficult, if not impossible, to obtain insurance on cargoes of bulk grain. Railroad facilities at that time were limited, and sacked grain could be readily transported on flat cars. More recently the opening of the Panama Canal, the numerous advances in ship construction and

[1] Gordon Klemgard, wheat grower, Pullman, Wash., accompanied the party during part of the study and rendered valuable assistance in advising and criticizing the work from the standpoint of a practical wheat producer.

design, and a more adequate railway system have removed most of these early barriers to bulk handling of grain for export.

During the World War a scarcity of sacks developed, and the cost of sacks became so great that many growers shifted to bulk handling. Makeshift methods were used in this emergency since adequate bulk-handling equipment had not yet been introduced in the region. Practically no facilities were available at the country shipping point for handling grain in bulk. Growers hastily constructed crude farm-storage plants, most of which lacked efficient equipment for elevating the grain in and out of storage. Considerable shovel work was necessary, and much of the expected saving in bulk handling was dissipated through the inefficient methods used.

FIGURE 1.—PERCENTAGE OF WHEAT RECEIVED IN BULK AND EXPORTED IN BULK FROM COLUMBIA RIVER AND PUGET SOUND TERMINAL MARKETS, 1923-24 TO 1929-30

Bulk wheat has formed an increasing proportion of the receipts of wheat at these markets from the Pacific Northwest during late years, but much of the sacked wheat received must still be bulked at the terminals for export. Ships are not taking sacked wheat to the extent they did even 10 years ago. (Prepared from records of the Pacific Coast headquarters Federal grain supervision.)

After the war, with the introduction of combine harvesters equipped to handle sacked grain, growers largely returned to sack handling. Although the quantity of grain exported in sacks from terminal points in Washington and Oregon is now a negligible quantity, 62.7 per cent of all wheat received at Columbia River and Puget Sound terminals in the 1929–30 crop year arrived in sacks. (Fig. 1.) Bulk versus sack handling has recently become a live issue with growers over this entire region. The necessity under present conditions for cutting production costs to the minimum, the obvious difference in physical exertion required by the two methods, the development of more adequate bulk-harvesting equipment, and the gradual enlarging of terminal facilities for handling bulk grain are the main factors causing this revival of interest. In certain areas of gently rolling or level land, where facilities for handling and storing bulk grain have been provided at the shipping point, many growers have recently changed to bulk handling or contemplate changing in the near future.

SCOPE AND METHOD OF THE STUDY

This study seeks to determine the relative economy in harvesting and handling grain on farms, by sack and by bulk methods, under hilly conditions and in areas of level or gently rolling land. Particular attention is given to types and costs of bulking equipment which have proved most satisfactory under varying conditions of topography. The cost and feasibility of storing bulk grain on the farm is considered, as well as the important question of the relation of present storage and handling facilities at local and terminal points to the problem of shifting from sack to bulk handling on the farm.

Three hundred and sixteen growers scattered over the important grain-producing areas of eastern Washington, eastern Oregon, and northern Idaho were interviewed in the summer of 1930. About half these men, who were handling grain in bulk, estimated their costs in converting sacking equipment for bulk handling of grain. They also supplied data on the size of the bulk combine-harvester, its motive power, number and wage of men used in its operation, and acres harvested daily and during the 1929 season. Similar information was obtained from the interviewed growers who were handling sacked grain.

The organization for hauling the grain was studied, such factors as the following being considered: Distance from shipping point, number of trucks owned and the estimated expense for their operation, contract rates if the hauling was hired, number of bushels hauled per season and per day, and whether the grain went directly to the shipping point or was placed first in farm storage.

An attempt was made to compare those factors most likely to cause delay in combine operation under the two handling methods. The study included estimates of the quantity of grain wasted in harvesting by each method. All factors affecting farm costs for harvesting and handling grain by each method were considered, except the expense involved for use of combine and tractor or horses that pulled it. Although the weight of the bulk tank will increase to some extent the expense for gasoline, oil, and repairs, the cost per hour of use, when figured on the bushel basis, would not be greatly different from costs in operating the combine under sack harvesting. Opinions of managers of bulk elevators and sack warehouses at many of the important country shipping points were obtained on the merits of sack and bulk handling methods. Terminal facilities in Washington and Oregon were inspected, and information was gathered on present capacities for bulk and sack grain and probable adequacy in the event of a decided shift from sack to bulk handling on the farm.

COMPARISON OF SACK AND BULK HANDLING METHODS[2]

COST OF MAN LABOR IN COMBINING GRAIN

One of the important savings in bulk harvesting of grain is in the cost of man labor in operating the combine. A common crew used with the sack combine includes a sack sewer, sack jigger,

[2] For information concerning the costs and advantages of bulk and sack handling methods at the terminal markets and for export see the following publication: BATES, E. N., BODNAR, G. P., and STIRNIMAN, E. J. BULK AND SACK HANDLING OF GRAIN IN THE PACIFIC COAST STATES. U. S. Dept. Agr. Circ. 161, 28 p., illus. 1931.

separator man, header tender, and driver of tractor or team. (Fig. 2.) When yields are light the sack sewer can jig the sacks, thus eliminating one man. Occasionally the jobs of separator man and header tender can be combined.

The corresponding bulk crew under normal-yield conditions is composed of three men—separator man, header tender, and driver of tractor or team. With light yields the jobs of tending header and separator are performed by one man, and a few farmers harvesting on level land operate the bulk combine with one man. (Fig. 3.) This is accomplished by handling the tractor from the combine, using reins attached to the tractor controls. Crews for bulk combining range from one to four men, whereas three to five men are required in operating a machine with sack equipment.

FIGURE 2.—The usual 5-man crew used in combining grain by the sack method. This crew was able to cut, thresh, and sack 1,000 bushels of wheat in a 10-hour day on fields averaging 33 bushels per acre

Bulk harvesting may result in less out-of-pocket expense for hired labor than harvesting by the sack method. With fewer men in the bulk crew a larger part of the labor may be supplied by members of the family. The necessity for hauling the grain simultaneously with "combining" in bulk may operate to reduce this advantage. If the grain is hauled with a single truck, however, the maximum bulk-harvesting crew, including truck driver, is still less than the crew needed on the sack combine exclusive of hauling operations. (Table 1.) The elimination of handling sacks in harvesting bulk grain materially reduces the physical exertion that must be expended by the combine and hauling crews. Frequently immature family labor is utilized to replace the robust hired hand required in sack handling.

Table 1 shows the cost of man labor in combining grain. This cost was calculated for each farm studied by multiplying the daily wage for the combine crew (giving family labor the same wage as hired hands) by the number of days the combine was operated. This cost, divided by the number of acres combined, gives the cost per acre for man labor in combine operation on the individual farm. Man-labor costs, as shown in Table 1, are weighted averages obtained by adding the total costs for all the farms in each group and dividing by the total acreage combined by the entire group. Records are classified according to method of handling, size of combine, and topography of land. Most of the wheat land in eastern Oregon, the western part of eastern Washington, and the Grangeville area in Idaho, may be classed as level or gently rolling. The eastern part of the wheat-producing area in Washington and the adjacent territory in Idaho is sufficiently hilly to require special adaptations of bulking equipment. The more level areas of the wheat belt in Oregon and Washington

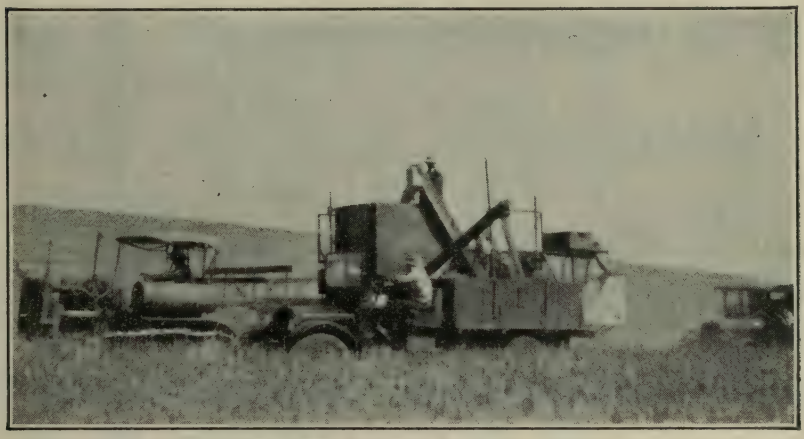

FIGURE 3.—A bulk-handling crew of 2-men, 1 on the combine and 1 driving the tractor. This crew was able to harvest 1,000 bushels of wheat in 10 hours on fields averaging 33 bushels per acre. With the aid of the two trucks shown, the grain was all under cover at the country shipping point at the end of the day

are also the areas of lowest precipitation. Consequently crop yields in this territory average measurably less than those in the hilly area where precipitation is more bountiful.

Both tractor-drawn combines and horse-drawn combines are studied in Table 1. Since more men are necessary to operate the sack combine, this table indicates higher costs for man labor in harvesting by the sack method. Topography of land, length of cutter bar on the combine, and type of power drawing the machine all affect the acreage that can be harvested in a day. Under hilly conditions these factors tend to reduce the acreage combined in a day below that which could be expected with similar equipment operating on level land. Consequently man-labor costs per acre are higher in harvesting by either sack or bulk methods under hilly conditions. Similarly, Table 1 shows increases in man-labor cost as length of cutter bar decreases and when horses rather than tractors draw the combine.

TABLE 1.—*Cost of man labor in combining grain by sack and bulk methods under hilly and level conditions in Washington, Oregon, and Idaho, 1929*

TRACTOR-DRAWN COMBINES

Item	Combines 12 to 15.9 foot cut				Combines 16 to 19.9 foot cut				Combines 20-foot cut and over			
	Sack		Bulk		Sack		Bulk		Sack		Bulk	
	Hilly	Level	Hilly	Level	Hilly	Level	Hilly	Level	Hilly	Level	Hilly	Level
Records studied—number	9	14	7	21	9	15	7	35	(1)	10	(2)	10
Acreage cut per day—acres	23.11	25.91	23.45	26.54	30.91	34.03	30.97	33.03	.....	47.45	.....	41.71
Men in crew [3]—number	4.70	3.00	2.90	2.80	4.90	4.50	3.30	3.30	.....	5.20	.....	3.40
Percentage of crew which is family labor [4]—per cent	16.67	28.00	35.00	32.76	9.10	23.53	8.70	25.86	.....	21.15	.....	5.88
Man labor per acre—hours	2.03	1.39	1.24	1.06	1.59	1.32	1.07	1.00	.....	1.10	.....	.82
Cost of man labor: [5]												
Per acre—dollars	1.27	.99	.95	.76	1.10	.92	.79	.69	.....	.78	.....	.67
Per bushel—cents	5.28	4.59	3.23	2.70	4.24	4.70	2.67	2.56	.....	3.75	.....	2.21

HORSE-DRAWN COMBINES

Records studied—number	31	27	11	14	24	14	10	19	.....	6	.....	5
Acreage cut per day—acres	22.76	24.21	20.40	22.48	25.70	29.17	28.26	30.35	.....	48.68	.....	42.01
Men in crew [3]—number	4.70	3.90	2.90	2.90	4.90	4.10	3.30	3.10	.....	4.20	.....	3.40
Percentage of crew which is family labor [4]—per cent	14.48	29.52	28.12	40.00	18.75	31.58	27.25	34.48	.....	24.00	.....	11.78
Man labor per acre—hours	2.07	1.61	1.42	1.29	1.91	1.41	1.17	1.02	.....	.86	.....	.81
Cost of man labor: [5]												
Per acre—dollars	1.50	1.07	1.11	.86	1.38	1.02	.95	.71	.....	.78	.....	.66
Per bushel—cents	4.65	4.84	4.53	3.18	4.78	4.71	4.12	3.10	.....	3.96	.....	3.14

[1] Three farms—too few to average.
[2] Two farms—too few to average.
[3] Bulk crews on the combine usually range in size from 1 to 4 men; sack crews, from 3 to 5 men.
[4] Percentages are not entirely consistent because of the small number of cases dealt with; but they serve to illustrate the possibilities in reduction of cash cost.
[5] Family labor was valued at the going wage plus board and includes labor of operator as well as of other members of family.

Higher yields in some of the hilly areas tend to reduce per bushel costs for man labor in combine operation below those on level land with lower yields per acre.

COST OF HAULING

The cost of hauling a bushel of bulk grain a mile was slightly higher than the cost for sacked grain on farms on which the growers hauled with their own trucks. This relationship held true for short, medium, or long hauls. (Table 2.) Bulk hauling of grain is *easier* but not *cheaper* than hauling in sacks. Since bulk grain in most cases is transferred directly from combine to truck, it is essential that the truck be on hand to receive the grain as soon as the bulk tank on the combine is filled, or costly delay results. Although bulk grain is loaded and unloaded from the truck with ease and speed, it seems evident that in most cases the advantage gained in these operations is offset by time lost in attendance on the combine. With lighter-than-normal yields the longer delay before the truck has a full load would tend further to increase bulk-hauling costs. The grower should give careful attention to organizing his hauling operations to reduce this loss of time to a minimum.

TABLE 2.—*Cost of hauling bulked and sacked grain where the grower hauls with his own trucks; farms in Washington, Oregon, and Idaho, 1929* [1]

Length of haul and method of handling	Records	Average length of haul	Hauling cost per mile [2]	
			Per bushel	Per ton
0–3.9 miles:	*Number*	*Miles*	*Cents*	*Cents*
Bulk	31	2.31	1.31	43.66
Sack	8	2.22	1.28	42.66
4–7.9 miles:				
Bulk	25	5.48	.52	17.33
Sack	17	5.56	.49	16.33
8 miles and over:				
Bulk	16	11.13	.31	10.33
Sack	13	11.19	.28	9.33

[1] The average cost for use of owned trucks studied was $1.47 per hour, including driver. This rate has been applied to all trucks in this table.
[2] Median cost is used as most representative of the majority of individuals in each group.

Hauling grain in sacks is more laborious, but no time is lost in waiting for a load as the hauling job is entirely independent of the combine under sack-harvesting methods. Sack hauling may be postponed until the grain is all harvested, enabling the grower to utilize family labor and thus reducing out-of-pocket expense. The physical exertion required, however, may prevent the use of family labor unless it is capable of standing the strain of this task.

Although the cost per bushel increases with distance of haul, the cost for hauling a bushel of grain a mile is shown in Table 2 to decrease with increasing distance in hauling either bulked or sacked grain. That part of the cost represented by the charge for loading and unloading becomes smaller as the distance of the haul increases. Each grower supplied information on the expense involved in operating his trucks for the year, and estimated the total hours of use for the period. The weighted average cost of $1.47 per hour of

truck use has been applied to all trucks considered in Table 2. By thus eliminating the influence of varying individual costs for use of truck, Table 2 shows more clearly the effect of distance of haul and differences due to hauling in bulk and in sacks.

Contract rates for hauling sacked and bulked grain tend to average higher than costs where the grower does his own hauling. (Table 3.) Contract rates for bulk hauling are shown to average less than rates charged for sack hauling on the longer hauls. The hauling of bulk grain by contract is comparatively new over most of the region studied, and charges are still variable. In individual cases where the grower has good bargaining ability and under present conditions of cut-throat competition for hauling jobs, the grower may hire more cheaply than he could operate an owned truck. In handling grain in bulk, sufficient trucking facilities must be provided to insure against delay in combine operation in years of normal yields. Where yields vary widely from year to year it would appear wiser to depend on hiring part of the crop hauled when yields are rather heavy than to purchase an extra truck that would be used but little when yields are light. Size of farm, size of combine, distance from shipping point, and the amount of other truck work available during the year should all be considered before buying equipment for hauling.

SOURCES OF HARVESTING LOSS

A certain quantity of grain is inevitably lost in harvest and hauling operations. It is impossible to determine the exact measurement of losses inherent in each method of handling. It appears, however, that greater possibilities of loss are present when grain is handled in the sack. The main sources of loss in each method of handling and in order of importance are as follows:

Nature of the loss	Percentage of group reporting significant loss
Harvesting by the sack method:[3]	
Breaking of defective sacks	73
Leakage of grain from sacks in handling	71
Brushing grain off top of sack before sewing	60
Sacks of grain lost in high stubble	55
Sacked grain stolen from the field	32
Livestock foundering on sacked grain lost in high stubble	30
Injury by pests to sacked grain lying in the field	19
Weather injury to sacked grain lying in the field	17
Sacked grain destroyed in stubble fires	11
Harvesting by the bulk method:[4]	
Trucks or wagons leaking	11
Transferring grain to and from farm storage[5]	10
Transferring grain from combine to wagon or trucks	9

Practically all the growers now handling grain in bulk have had prior experience in sack handling. This group was nearly unanimous in the opinion that more grain is lost when the sack system is used. Bulk losses are relatively insignificant, and the sources of loss are mainly under the grower's control. Many of the losses in sack handling are beyond the control of the grower. (Fig. 4.)

[3] This group includes 236 growers experienced in harvesting by the sack method.
[4] This group of 137 growers has had experience both in bulk and sack handling; 91 per cent of them stated that there are greater losses of grain in sack handling.
[5] Farm storage may or may not be part of the bulk-harvesting program.

TABLE 3.—*Cost of hauling bulked and sacked grain where the truck work is contracted; farms in Washington, Oregon, and Idaho, 1929*

Length of haul and method of handling	Records	Average length of haul	Hauling cost per mile [1]	
			Per bushel	Per ton
0–3.9 miles:	*Number*	*Miles*	*Cents*	*Cents*
Bulk				
Sack	20	2.08	1.08	36.00
4–7.9 miles:				
Bulk	20	5.10	.62	20.66
Sack	18	5.36	.56	18.66
8 miles and over:				
Bulk	10	12.10	.35	11.67
Sack	8	12.50	.41	13.67

[1] Median cost is used as most representative of the majority of individuals in each group.

In certain large areas of the region studied, weather during the harvest period is likely to be hot with extremely low humidity. Under such conditions grain lying out (fig. 4) may lose weight in a very short time. This condition alone has influenced some growers to adopt bulk-handling methods.

SOURCES OF DELAY IN HARVESTING

The combine is seldom operated steadily for any great length of time. Delays, more or less serious in nature, make for a certain amount of enforced idleness. Sources of delay inherent in each handling method and the order of their importance are as follows:

Nature of the delay	Percentage of group reporting significant delay [6]
Harvesting by the sack method: [7]	
Repairing torn or snagged sacks	20
Breaking of defective sacks when jigged or dumped	15
Sack sewer not sufficiently trained for the work	14
Sacks fall off combine; must be set up to avoid losing in stubble	13
Irregularity in supplying sacks	13
Inability of sewer and jigger to handle grain in heavy yields	12
Breaking of defective twine while sewing sacks	10
Harvesting by the bulk method: [8]	
Stopping to transfer grain from combine to wagon or truck	27
Congestion at elevator, preventing trucks or wagons from returning on time	27
Trucks break down and fail to return on time	11
Unloading device on combine breaks down	8
Yield too heavy for size of equipment	6
Combine sticks on the hills because of too heavy load in bulk tank	4
Combine breaks down because of too heavy load in bulk tank	4
Elevating device at farm storage bin breaks down	4
Distance of haul too great for number of trucks	3
Gas engine on elevating device at farm storage breaks down	3
Tank on combine is too small; too frequent unloading	1

[6] Fifty-eight per cent of the growers harvesting by the sack method reported no significant delays experienced; only 21 per cent of those harvesting by the bulk method made a similar report.

[7] This group is composed of 212 growers experienced in using sack combines; 56 of these estimated an average loss of 22 minutes per 10-hour day directly attributable to the sack-harvesting method.

[8] This group is composed of 144 growers using bulk combines; 67 of these estimated an average loss of 38 minutes per 10-hour day directly attributable to the bulk-harvesting method.

Of the growers sacking their grain, 58 per cent stated that their delays were too insignificant to consider. Only 21 per cent of those using the bulk method made a similar statement. Apparently possibilities of delay are greater in handling grain in bulk. In addition to delays caused by 1½ to 2½ tons extra weight in the filled bulk tank, bulk combining is dependent on synchronizing the operation of the combine with the operation of the trucks or wagons. Trucks are frequently forced to wait in line to unload at the elevator, or break downs on the way prevent returning on schedule. This important source of delay is not experienced in harvesting by the sack method, in which combining and hauling operations are entirely independent of each other.

With certain makes of combines it is possible to retain sacking attachments when the bulk tank is mounted on the combine. By carrying a supply of sacks, a temporary shift from bulk to sack

FIGURE 4.—Sacked grain lying where dropped from the combine, subject to loss by theft, stubble fires, weather injury, and pests. The period of exposure ranges from a few days to several weeks

handling can be easily made and delay avoided when trucks or wagons fail to return on time. Quick shifts from bulk to sack combining are also desirable if custom work is done and in cases in which seed grain is sacked for storage.

LABOR REQUIREMENTS IN LOADING CARS

The smaller crew and lessened physical exertion required in combining by the bulk method are characteristic of all subsequent handlings of the grain. Figure 5 illustrates the ease and speed with which bulk trucks are emptied at the country elevator.

Fifty-one managers of country elevators estimated that on an average 2.91 hours of man labor were required to load an 80,000-pound car of bulk grain. This included the time necessary to cooper the car in preparation for its load of bulk grain.

Seventy-three managers of sack warehouses estimated that on an average 11.60 hours of man labor were required to load a car of the same size with sacked grain. This includes labor in tearing down piles of sacks preliminary to loading. It would appear from these estimates that practically four times as much man labor is required in loading cars of sacked grain, to say nothing of the much greater

expenditure of physical energy for each man-hour of work. Observations of unloading operations at terminal points indicate a similar conservation of labor and effort under bulk-handling methods.

BULK-HANDLING EQUIPMENT FOR THE FARM

COST OF OPERATION OF EQUIPMENT IN BULK-HANDLING DIRECTLY TO SHIPPING POINT

Growers who own sack combines and trucks can convert their equipment with relatively little expense to permit bulk handling. Sack attachments on the combine must be replaced by a bulk tank, and the substitution of a grain-tight truck box for the flat rack used in hauling sacked grain completes the essential equipment. In areas in which bulk handling is new, most growers are forced to provide

FIGURE 5.—Dumping a truck load of bulk grain at the country elevator. The scale platform is lifted by an air hoist to permit the truck to discharge grain at the end gate by gravity; a quick method involving a minimum of man labor

their own hauling facilities. Where bulk handling is well established, facilities are available for hauling bulk grain by contract should it seem desirable.

The 1929 cost of operating bulk equipment on the farms studied is presented in Table 4.

TYPES AND COST OF BULK-HANDLING EQUIPMENT

BULK-GRAIN TANKS (see pp. 14 and 15)

Most of the bulk tanks in use are mounted on the combine. Manufacturers are now giving greater attention to location of the tank with respect to obtaining a low center of gravity and a more uniform distribution of the added weight. Consequently bulk combines of the later models (fig. 6) are much better adapted than were the former models to use on hilly fields. The auger delivery is almost as speedy as the gravity system and permits unloading when the truck or wagon bed is considerably higher than the level of the bottom of the bulk tank. Early attempts at auger delivery were not wholly satisfactory, but on late-model machines the device seems thoroughly reliable.

TABLE 4.—*Cost of operation of equipment essential for harvesting grain in bulk in Washington, Oregon, and Idaho, 1929*

Item		Bulk tank on combine	Truck chassis	Truck box
Records	number	99	103	145
Capacity	bushels	55	(1)	86
Cost when purchased	dollars	106.42	1,075.25	48.00
Age in 1929	years	2	3	3
Estimated total life	do	11	6	12
Cost, 1929, for:				
Depreciation [2]	dollars	10.10	177.12	4.78
Repairs	do	.80	64.52	.44
Insurance	do		9.15	
License and taxes	do		31.40	
Gas, oil, and grease	do		94.72	
Interest [3]	do	5.52	41.66	2.22
Total	do	16.42	418.57	7.44
Amount chargeable to bulk handling [4]	do	16.42	159.14	6.92
Cost per bushel handled in 1929	cents	.12	1.75	.08

[1] 61 were 1-ton trucks; 31 were 1½-ton trucks; 10 were 2-ton trucks, and 1 was a 3-ton truck.
[2] Straight-line depreciation was figured; a machine having an estimated life of 10 years would have a depreciation charge of one-tenth its original cost during each year of its life.
[3] 6 per cent interest was charged on the average value of the equipment in 1929.
[4] Only a portion of the year's expense on truck chassis and truck bed is chargeable to handling grain since this equipment was used for other purposes during the year.

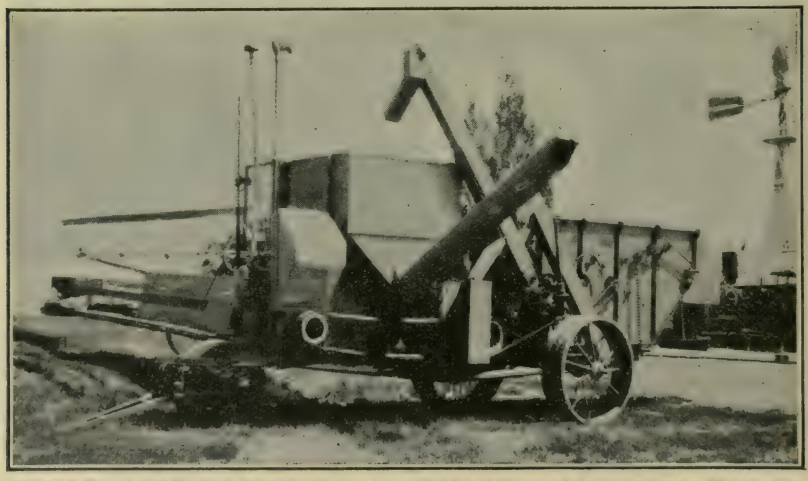

FIGURE 6.—A 65-bushel bulk tank on one of the later model combines. The auger delivery empties the tank in one and one-half to two minutes. The tank is mounted directly over the feeder house to secure a low center of gravity. Bulk or sack attachments are optional on this machine. A tank of this size costs $150 when bought separately

A homemade bulk tank that empties by gravity is shown in Figure 7. Although its weight is rather evenly distributed, the center of gravity is necessarily higher than that of the tank shown in Figure 6.

Bulk tanks bought separately to be installed on sack combines range in price from $105 to $190 in this region, depending on the make of the machine and the type and size of the tank (30 to 65 bushels). In selling new combines three out of five manufacturers furnish bulk or sack attachments at the option of the purchaser. Two manufacturers make an added charge for the bulk tank, but

this charge is lower than when the tank is bought separately to attach to a sack machine. The average purchase price of the bulk tanks mentioned in Table 4 is somewhat low because of the inclusion of homemade tanks with those bought as standard equipment.

Most of the older combines were not built to stand the extra weight of a tank full of grain. Care must be taken to truss these machines when the bulk tank is added. Truss rods may add $10 to $25 to the cost of equipping.

Under level or moderately rolling conditions bulk tanks of the type shown in Figure 8 give satisfaction. This tank mounted in a heavy V-shaped frame and supported above an old combine wheel, is coupled to the fore part of the combine. One I beam is attached in upright position to the side of the combine near the left rear wheel, and another is bolted in horizontal position to the inner side of the bulk tank. An ingenious coupling connects the two I beams and permits the bulk tank to level vertically and horizontally entirely independent of the combine. Sacking attachments are left on the machine which may be easily converted for either method of handling since the bulk tank is readily detached.

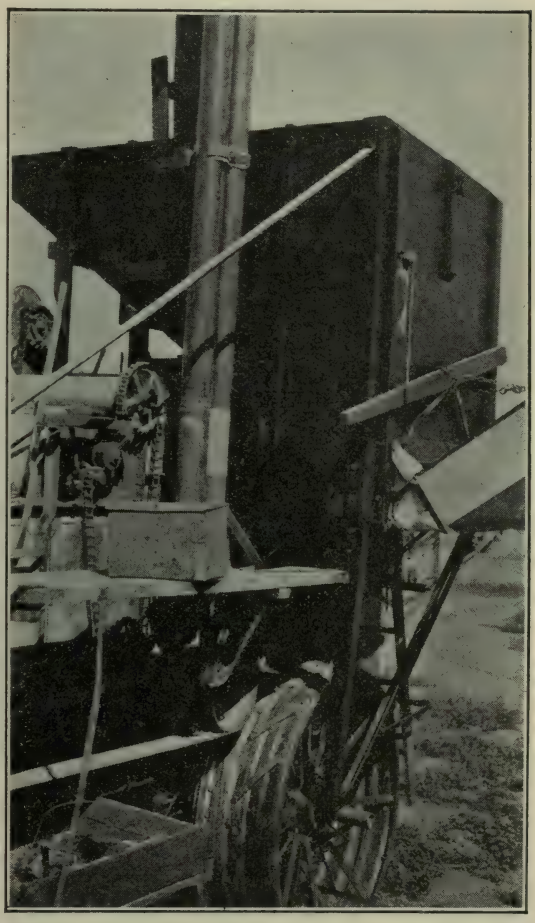

FIGURE 7.—A homemade bulk tank, gravity dump, 92-bushel capacity; cost, $127. Half the weight is suspended between the rear wheels of the combine and half hangs over the left side. The left rear wheel has been widened 6 inches, and a roller bearing has been substituted for the plain bearing. This machine operated successfully on soft ground and under rather hilly conditions

This type of bulk tank is probably easier on the older combines than on those combines in which the weight is supported directly by the combine frame. Some slight tendency toward side draft is developed, but the cost of the tank, ($450–$550 as made up in an eastern Oregon town) is the chief disadvantage. Data obtained on 14 bulk tanks of this type show an average expense of $63.67 per tank in 1929—almost four times the year's expense on the bulk tanks shown in Table 4.

Under level conditions, wagons trailed at the side of combines may serve as bulk tanks. (Fig. 9.) Empty wagons replace filled ones which are hauled direct to the shipping point, or the grain may be transferred to trucks.

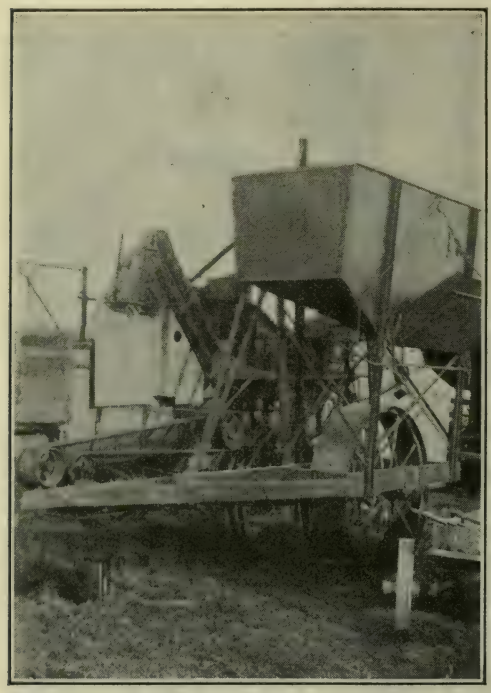

FIGURE 8.—A 100-bushel bulk tank mounted at the side of the machine on an old combine wheel. Suitable for level and moderately rolling conditions. (See text for more adequate description)

TRUCKS FOR HAULING

Trucks of 1 to 1½ ton capacity are most commonly used for grain hauling in this region. The 1930 delivered price for a 1½-ton truck of the most popular make was $750. This price included dual wheels and cab but no truck bed. The second most popular make with similar equipment retailed at $800 delivered. Four wheels instead of six were furnished at a reduction of $25 in both cases. Truck beds for bulk or sack hauling were built by the grower or were bought from the local blacksmith. If the work is hired done, $40 to $50 may be spent for a truck box holding 70 to 80 bushels of bulk grain. As a result of the swing toward truck hauling, country dealers are frequently overstocked with bulk wagon boxes. These may sometimes be bought at considerable reductions and cut down to the desired length for truck use.

FIGURE 9.—Bulk grain being delivered to a wagon trailed at the side of the combine. The filled wagon is exchanged for an empty one returned from the shipping point. A simple and efficient method for use on level land

The floor of the box may be oiled or covered with metal to reduce friction and to speed the flow of grain when being dumped at the elevator. Growers can equip trucks with flat racks and tight-fitting sideboards. After hauling is completed, the sideboards are removed to permit other types of hauling during the year. Especial care must be exercised in bolting down sideboards, or a leaky truck box results.

Figures 10 and 11 illustrate the extremes in style of truck-bed construction. Either would give satisfaction on level land, but the top-heavy type (fig. 11) would prove dangerous on hillsides similar to those shown in Figure 12.

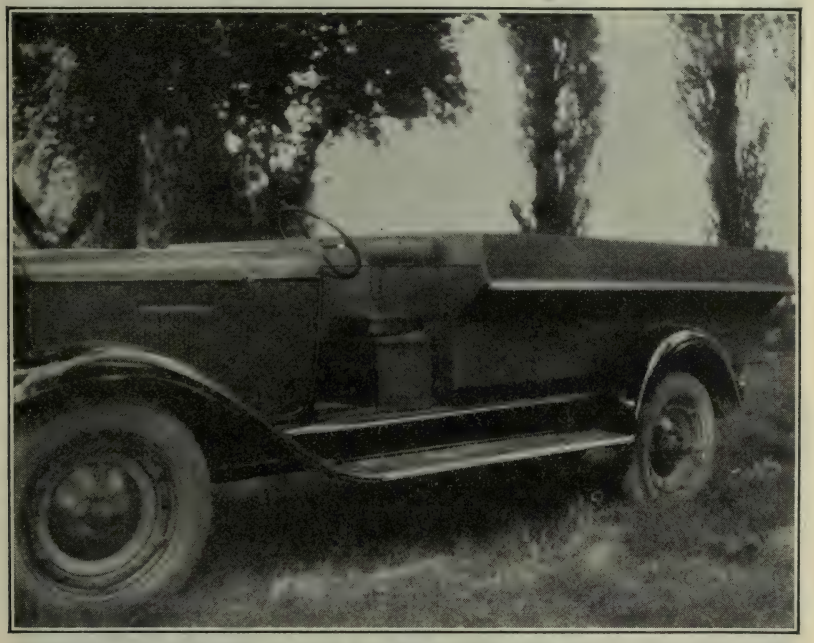

FIGURE 10.—A good type of truck box for hauling bulk grain under hilly conditions. The shallow box, built unusually wide, provides a low center of gravity without sacrificing capacity. The cab is omitted for greater safety of the driver in event of an upset. Welded-steel construction insures against loss of grain by leakage. Capacity of truck box, 80 bushels; price, made by blacksmith, estimated at $75

The investigator in Figure 12 is holding a level on a straight edge at the end of the truck to show how much grain could be carried without spilling. More than half the capacity of the truck is lost in operating on hills of this slope. The addition of sideboards would increase the capacity, but the center of gravity might shift to a dangerous degree. Under hilly conditions grain must be transferred where slopes will permit combine and truck to contact in safety. Several contacts may be necessary before the truck has a full load. The alternative is to take the grain from the combine with teams and wagons for transfer to trucks at the foot of the slope.

TRANSFER BINS

If hills are steep, bulk grain may be taken from the combine with teams and wagons and elevated into a transfer bin at the foot of the

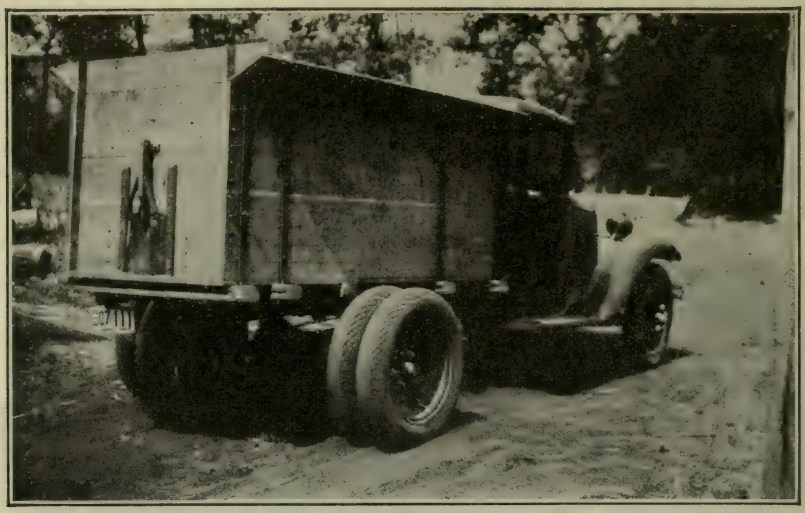

FIGURE 11.—A poor type of truck-box construction for any but level conditions. The too narrow and deep bulk box has a high center of gravity, which increases chances for an upset. Dual rear wheels furnish greater traction and tend to prevent the load from cutting too deeply into the soil

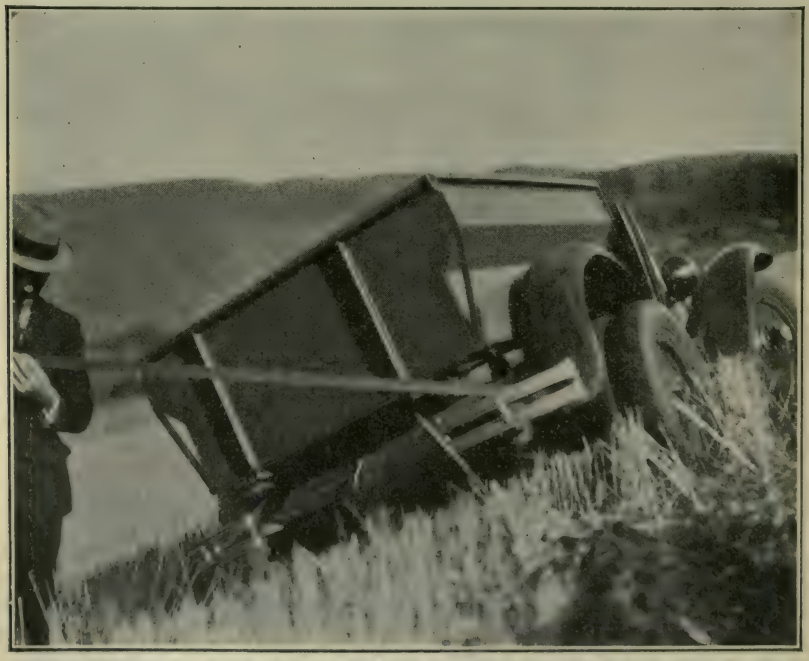

FIGURE 12.—The capacity of this truck for hauling bulk grain is reduced by more than half by the steepness of the slope. This problem should not be overlooked when planning to take grain directly from the combine with trucks

slope. Farms at considerable distance from the shipping point may employ transfer bins to act as reservoirs, permitting all grain to be hauled with a single truck. In Figure 13 the gas engine used to operate the elevating device is placed on top of the bin, out of the

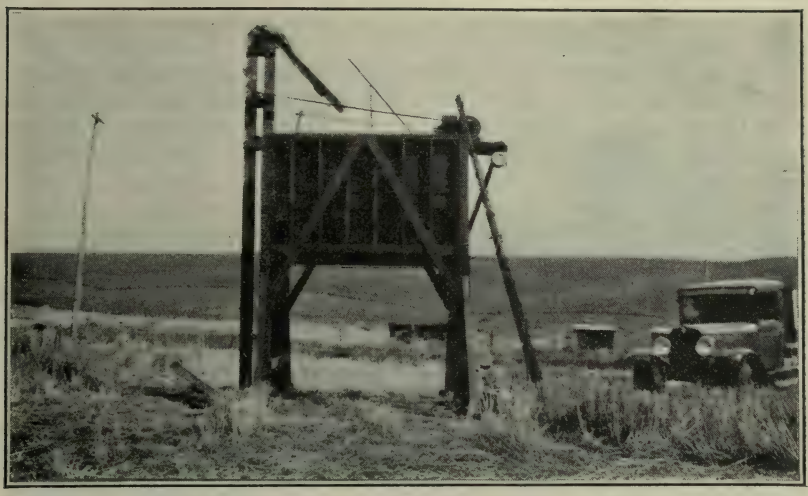

FIGURE 13.—A hopper-bottom grain-transfer bin mounted on skids to permit moving from time to time, thus making it possible to maintain short hauls from the combine. Note the unusual location of the gas engine

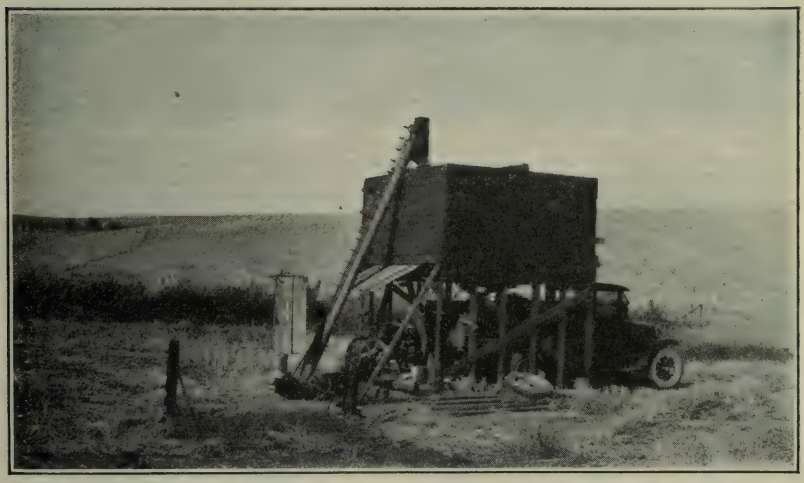

FIGURE 14.—A portable transfer bin showing truck in place ready to be loaded. The type of elevating device shown costs $150 and up, depending on size and attachments. The most common size of bin is 400 bushels and material costs average $50

dust. It is bolted securely in place and needs no attention when the transfer bin is moved. Vertical elevating devices of the type shown may be had in lengths varying from 10 to 30 feet at prices ranging from $75 to $125.

Figure 14 shows the truck in position to receive a load of grain from the bin. The wagon jack in the foreground elevates the front part of the wagon to facilitate dumping at the end gate.

Transfer bins are built with 400 to 500 bushel capacity and materials cost from $40 to $60. Bins of this size will hold nearly all the grain combined in half a day and thus insure against delay in case of truck breakdown.

Bins of the general type shown in Figures 15 and 16 are very satisfactory for use in the hills. The bin is filled and emptied entirely by gravity. Operating costs for bins of this type are much less than if man labor must be employed and fuel purchased to operate an elevating device.

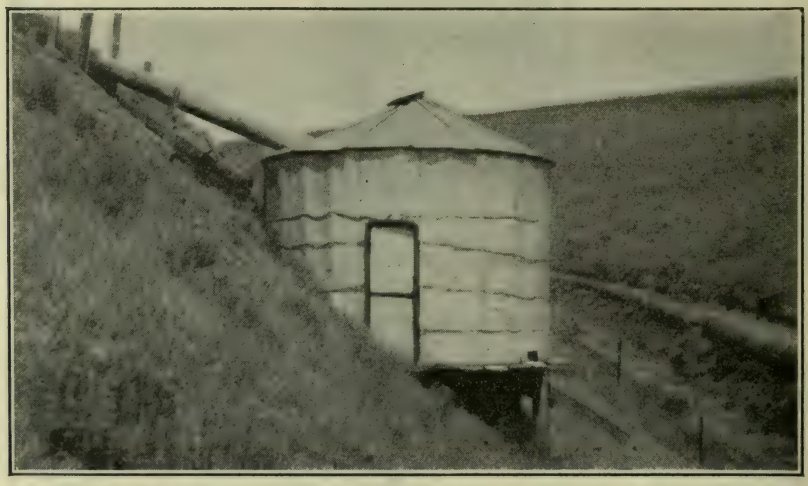

FIGURE 15.—The grower can haul a considerable distance to the shipping point with only one truck with this bin as a temporary reservoir. The hillside location permits filling and emptying the bin by gravity, thus eliminating a gas engine and elevating device. Capacity of bin, 1,100 bushels; cost, $158

A common type of bulk wagon is shown in Figure 17. The owner has added some simple yet ingenious devices making for greater safety and more efficient operation under hilly conditions.

SAVINGS THROUGH BULK HANDLING DIRECT TO SHIPPING POINT

The various factors that make up the cost of combining and hauling grain direct to shipping point, by sack and bulk handling methods, are brought together in Table 5. The cost of using the combine is not considered; although the weight of the bulk tank will increase to some extent the expense for gas, oil, and repairs, the cost per hour of use when figured on the bushel basis would not be greatly different from cost of operating the combine in sack harvesting. Savings due to bulk-handling methods in 1929 ranged from 3.8 to 4.7 cents per bushel, varying with length of haul and topography. Sixty-eight to eighty-five per cent of the saving on these farms was due to eliminating the cost of the sacks. If sacks are used several times and if the grain is bulked at the elevator, sack cost per bushel is materially reduced and the margin of saving by

the bulk method is considerably lessened. In 1930 sacks cost 11 cents each, as compared with 13.5 cents in 1929. Had the 1930 sack price prevailed in 1929, savings due to the bulk method would have been lowered by 1.11 cents per bushel. Within reasonable limits, savings effected by the bulk method will tend to vary directly with the price of sacks. As sack prices decrease, savings by bulk handling likewise diminish; as sacks increase in price, savings by bulk handling become increasingly important.

FIGURE 16.—A wooden auxiliary roadside bin, loaded and unloaded by gravity. Capacity, 500 bushels; cost, $20

Table 5 indicates an average saving by the bulk method in 1929 of 1.6 cents per bushel for man labor in combine operation on the farms studied. This saving is second only to that resulting from elimination of expense for the sack and likewise varies in significance from year to year with increases and decreases in the scale of wages paid. Due chiefly to differences in cost of man labor for combine operation, greater savings per bushel accrue to bulk handling under level conditions than under hilly conditions. On level land the bulk combine

FIGURE 17.—A wagon used to bring bulk grain to a portable transfer bin where hills were too steep for trucks to contact the combine directly. The padded 2 by 12 inch plank may be slipped through strap-iron brackets to project from either side of the wagon. The weight of the driver seated at the end of this lever aids in balancing the load on hillsides. The chute is for side delivery of grain through the floor of the wagon box

is often operated by a 2-man and infrequently by a 1-man crew; under hilly conditions a larger crew is usually necessary for efficient work.

TABLE 5.—*Cost per bushel for harvesting sacked and bulked grain under hilly and level conditions and delivering it to the shipping point; farms in Washington, Oregon, and Idaho, 1929* [1]

Item of cost	Hilly conditions		Level conditions		Average	
	Sack	Bulk	Sack	Bulk	Sack	Bulk
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Man labor cost in operation of combine	4.61	3.60	4.41	2.67	4.51	2.91
Expense in 1929 of bulk tank on combine	-------	.11	-------	.12	-------	.12
Net cost of sack per bushel [2]	3.22	-------	3.22	-------	3.22	-------
Hauling cost per bushel (owned trucks, 0–3.9 mile hauls) [3]	2.84	3.03	2.84	3.03	2.84	3.03
Total cost in 1929 [4]	10.67	6.74	10.47	5.82	10.57	6.06
Saving per bushel by bulk method: [5]						
0–3.9 mile hauls	-------	3.93	-------	4.65	-------	4.51
4–7.9 mile hauls	-------	3.99	-------	4.71	-------	4.57
8-mile hauls and over	-------	3.80	-------	4.52	-------	4.38

[1] These average costs cover all records from which the data shown in previous tables were derived.
[2] The cost remaining after the 3-cent premium on sacked wheat is credited on original cost of the sack.
[3] No appreciable differences were found between costs of hauling under hilly and level conditions. The median cost for each group is used.
[4] Cost of use of combine not considered.
[5] Savings per bushel vary largely with the price of sacks from year to year. In 1929 sacks cost 13.5 cents each; in 1930 the cost was 11 cents, a difference of 1.11 cents per bushel in net cost of the sack in the two years.

TABLE 6.—*Cost in operation of equipment used for farm storage of bulk grain in Washington, Oregon, and Idaho, 1929*

Item	Farm-storage plants				Gas engines	Farm elevating devices [1]
	Stationary		Portable			
	Wood	Metal	Wood	Metal		
Records—number	33	20	8	7	45	43
Distance to shipping point—miles	5	6	7	11	-------	-------
Capacity—bushels	8,398	6,243	2,844	5,607	[2]	-------
Cost when purchased—dollars	1,374.08	740.00	258.00	646.40	128.97	159.78
Investment per bushel—do	.16	.12	.09	.12	-------	-------
Age in 1929—years	13	8	5	9	6	7
Estimated total life—do	35	32	12	30	15	18
Cost, 1929, for—						
Depreciation [3]—dollars	41.69	24.73	16.60	21.81	9.54	11.51
Repairs—do	2.09	1.61	1.25	-------	1.06	4.30
Insurance—do	3.55	.65	-------	-------	-------	.10
Gas, oil, and grease—do	-------	-------	-------	-------	14.13	-------
Interest [4]—do	52.72	33.02	7.86	27.61	4.78	6.07
Total—do	100.05	60.01	25.71	49.42	29.51	21.98
Amount chargeable to bulk-stored grain [5]—do	97.92	59.82	25.71	49.42	22.59	21.98
Cost per bushel stored in 1929—cents	1.17	.96	.90	.88	.18	.18

[1] 70 per cent of the elevating devices were of the drag type, 18 per cent cup type, and 12 per cent blower type.
[2] 12 per cent of these engines were under 3 horsepower in size; 71 per cent were 3–6 horsepower (6 horsepower being most common), and 17 per cent were over 6 horsepower in size.
[3] Straight-line depreciation was figured; a machine having an estimated life of 10 years would have a depreciation charge of one-tenth its original cost during each year of its life.
[4] 6 per cent interest was charged on the average value of the equipment in 1929.
[5] Only a portion of the year's expense on stationary storage plants and gas engines is chargeable to bulk-stored grain since these items were used for other purposes during the year.

Savings averaged somewhat less on farms having the longer hauls. This is possible because of the greater difficulty experienced in providing the proper hauling facilities and in timing their operations to prevent delay.

DISCARDING SACK EQUIPMENT

There have been comparatively few actual discards of sacking equipment in cases in which growers have shifted to bulk handling. In some cases sacking attachments on the combine have been sold. Growers who occasionally do custom work, preserve their sack equipment so they can use any method of harvesting the customer wishes. Others leave the sacking attachments on the combine as insurance

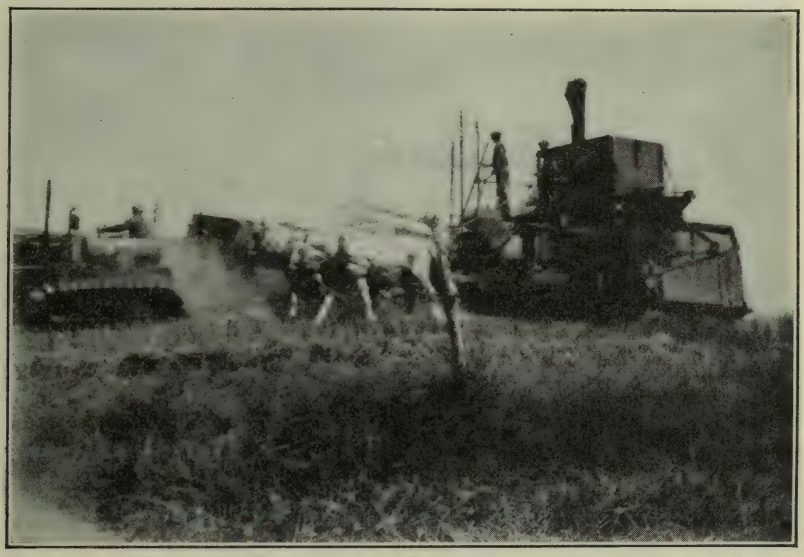

FIGURE 18.—This grower's tractor was too small to pull his converted sack combine after the addition of a bulk tank which held over 2½ tons of grain. Four horses were hooked between the combine and the tractor to provide extra power. The sacrifice of this tractor for a larger one would add materially to the grower's cost of shifting from sack to bulk handling

against delay, and many sack seed wheat for storage. A few growers replaced sack with bulk equipment only when the sack combine was ready to be discarded, thus reducing to a minimum the expense in making the shift.

Growers who replace horses with tractors, although still handling grain in sacks, may be confronted with the problem illustrated in Figure 18 if they shift to bulk-handling methods.

COST OF OPERATION OF EQUIPMENT FOR FARM STORAGE

Storage of bulk grain on the farm has not been practiced extensively over most of the region studied. The limited data available are presented in Table 6.

The cost of constructing farm-storage plants depends largely on the material of construction, capacity of storage, convenient supply of sand, gravel, and water, current price of lumber and labor, and whether the work is hired done or family labor utilized. Investments

per bushel in Table 6 are low because of the inclusion of second-hand with new equipment.

At prices current in 1930, 500-bushel portable metal bins cost $90 to $150 (an investment of 18 to 30 cents per bushel), depending on gage of metal used. Portable metal bins of 1,000 bushel capacity cost $125 to $200 (12.5 to 20 cents investment per bushel), depending on gage and quality of metal used. Foundations add $15 to $35 to the costs given above, depending on the type used.[9] At prices current in 1930 the investment in wooden farm elevators would range from 20 to 35 cents per bushel. Concrete farm storage at an investment of 40 to 50 cents per bushel seems prohibitive under most conditions.

FIGURE 19.—A completely equipped farm-storage plant located on an improved road which insures wheat delivery at any season. The capacity is 16,000 bushels; cost, $7,000; investment per bushel, 44 cents. Such investments bring too heavy a burden of overhead expense on all but the larger farms

Figure 19 illustrates one type of farm elevator. No expense was spared in constructing this plant and in providing every facility for efficient handling. The resultant investment of 44 cents per bushel saddles the grain enterprise with an unwarranted burden of overhead expense.

The plant shown in Figure 20 is well adapted to hilly conditions. Filling and emptying the storage is accomplished entirely by gravity, thus eliminating all expense involved in the operation and maintenance of an elevating device. The bin is filled by unloading wagons or trucks from the platform shown in the upper left-hand corner of the illustration. By driving under the small addition to the main storage bin, trucks are speedily loaded from the delivery spouts located there. This plant is of "crib" construction, the walls being 6 inches thick and built up by placing 2 by 6's on top of each other. With less than half the investment per bushel of the plant shown in Figure 19, this elevator is operated with greater efficiency and at less cost. Figure 21 illustrates a similar plant of metal construction.

[9] KELLEY, M. A. R., and BOERNER, E. G. FARM BULK STORAGE FOR SMALL GRAINS. U. S. Dept. Agr. Farmers' Bul. 1636, 46 p., illus. 1930.

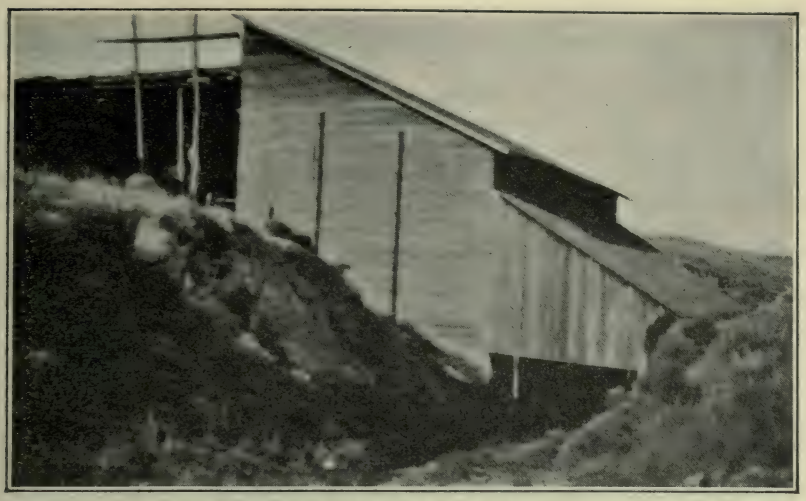

FIGURE 20.—A permanent farm-storage plant for hilly conditions, filled and emptied by gravity. The concrete floor has considerable slope, giving an easy flow to the delivery spouts. Opposite walls are reinforced with tie rods. Capacity of plant, 25,000 bushels; cost, $5,000

Tractors have replaced horses on many farms in this region. Under these conditions, well-constructed horse barns frequently stand unused. Some growers have converted lofts of such barns into storage places for bulk grain at comparatively little expense.

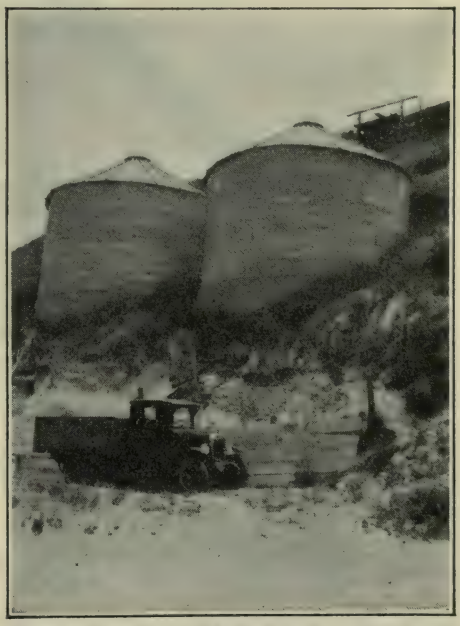

FIGURE 21.—A gravity load and unload farm-storage plant of metal construction. Each bin holds 3,000 bushels. Used steel bins were bought and placed in the hillside on concrete foundations at a total cost of $300 each

GAS ENGINES AND ELEVATING DEVICES

The size of gas engine used with elevating devices in farm storage depends to some extent on the nature of other work for which the engine may be used during the year. Over two-thirds of the gas engines used were 3 to 6 horsepower in size; 6 horsepower was the most common. Delivered prices for gas engines on skids in the region during 1930 were: 1½ horsepower, $70 to $90; 3 horsepower, $110 to $130; 6 horsepower, $190 to $210. If blowers are used instead of cup or drag elevators, a minimum of 3 horsepower is usually required. One blower manu-

facturer recommends an 8-horsepower engine. Some growers have used the motors from old automobiles to avoid the outlay for new gas engines.

Types of elevating devices in use are illustrated in Figures 14 and 22. All-metal portable elevators of the drag type (fig. 14) cost $150 and up, depending on the size and the attachments furnished. The type shown in Figure 22 sells for $100 to $130, depending on the size. Blowers of eastern manufacture retail at $160 to $180, delivered.

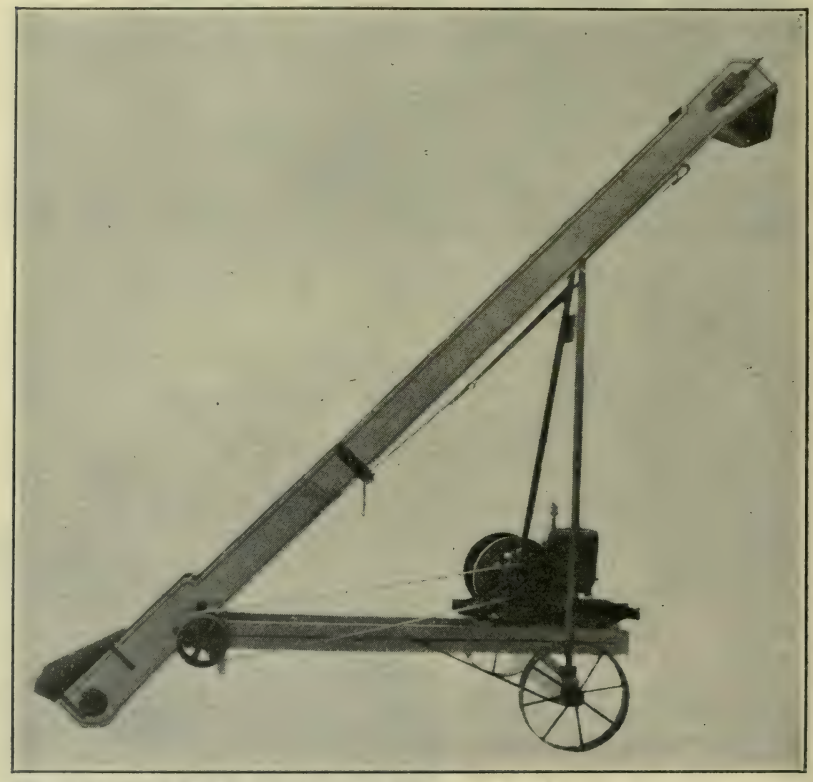

FIGURE 22.—This type of portable farm elevator is made in the Pacific Northwest at prices ranging from $100 to $130, depending on size. A flexible spout and a small hopper can be furnished as extras. Gas engines will add $70 or more to the investment, depending on the horsepower

Care should be exercised in purchasing elevating equipment to match the elevating device with the proper unit of power to insure transferring the grain with the maximum of speed and efficiency.

FEASIBILITY OF FARM STORAGE OF BULK GRAIN

This study included 147 growers who were bulking their grain. Only 69, or about 47 per cent, were equipped with stationary farm-storage plants. Forty-four of these sixty-nine, or approximately 30 per cent of the men handling grain in bulk, were actually using farm-storage facilities.

Factors that have retarded the development of farm storage in this region may be listed as follows:

In many cases, road conditions almost compel hauling at harvest time. With the coming of fall rains delivery of farm-stored grain would be uncertain, and advantageous opportunities for sale might be sacrificed. Although roads are constantly being improved, most growers must still haul at least part of the distance over dirt roads.

Growers who store grain at the country shipping point are issued warehouse receipts that are acceptable to bankers as collateral for loans. No receipts are issued on farm-stored grain in Washington, Oregon, and Idaho, which makes it very difficult to obtain loans on grain that is stored on the farm.

Many farm-storage plants were built during the World War when prices for grain sacks were very high. Most of these plants were inconvenient as it was necessary to shovel out much of the grain when the bins were emptied. Entrance of rain and snow because of faulty construction caused grain to spoil. Most of the idle storage plants to-day are of these earlier types.

Bulk grain must be handled twice when stored on the farm as compared with a single handling when trucked directly from combine to shipping point.

The investment in permanent farm-storage facilities is sufficiently great to prove a retarding influence in itself, and on the smaller farms the resultant burden of overhead expense is not easily borne.

Much of the region is farmed by tenants. Under these conditions neither landlord nor tenant cares to stand the expense of a permanent improvement.

Most growers must sell part of the crop at harvest time to meet expenses; hence a tendency develops to deliver the entire crop at that time.

The following may be mentioned as advantages in storing grain on the farm:

Hauling to the shipping point may be done with family labor and owned equipment after the rush period is over. Growers on the smaller farms frequently exchange work during the harvest season. Adequate hauling facilities are often provided in these ways without resorting to farm storage.

If a longer hauling period can be allowed, one truck can haul the crop normally hauled by two trucks direct from combine to shipping point.

Farm storage would tend to slow the present rush of bulk grain to the terminals at harvest time. If a sufficient volume of grain were held back, the present depressing effect of temporary gluts on price might be avoided.

The visible supply of grain at terminal points would be reduced.

The identity of the grain would be preserved, and premiums could be realized for high quality.

COST OF TRANSFERRING FROM COMBINE TO FARM STORAGE

Nearly all growers who were using farm storage transferred the grain from combine to storage with teams and wagons. Table 7 presents the average cost per bushel for this job on the farms studied.

The costs of 2.17 and 2.78 cents per bushel are nearly as great as the cost for hauling direct to shipping point, which is about 3 cents per bushel for the average haul. Data were not available for figuring costs in those instances in which the grain is transferred to farm storage with trucks. It seems likely that the cost would be equally great if not greater.

TABLE 7.—*Cost of transferring bulk grain by wagon from combine to farm storage in Washington, Oregon, and Idaho, 1929*

Item	Level land	Hilly land
Farms—number	15	13
Wagons used per farm—do	1.6	2
Distance to farm storage—miles	.70	.66
Time required for hauling, per farm—hours	120	154
Cost of haul to farm storage [1]—dollars	191.92	295.60
Quantity hauled—bushels	8,824	10,639
Cost per bushel for haul—cents	2.17	2.78

[1] Cost includes charge for use of wagon and wages for teams and drivers.

Trucks that haul bulk grain from farm storage are not dependent on combine operation as is the case when bulk grain is taken directly from the machine. It is doubtful, however, except where farm-storage bins are emptied entirely by gravity, if loading the truck from the bin could be accomplished as rapidly as loading directly from the combine. Under these conditions the average cost of hauling from farm storage to town would probably not be greatly different from the cost of hauling directly from the combine to town. Data are insufficient to determine this point statistically. In any event, farm storage introduces an extra handling which must operate to increase costs above what they would be if the grain were handled but once.

ESTIMATED COST OF FARM STORAGE

Various items of expense incurred in 1929 for storing bulk grain on the farms studied are assembled in Table 8. Costs of 4.24 and 4.89 cents per bushel were incurred, the higher cost being for storage under hilly conditions. Commercial rates for storing bulk grain at the shipping point are 10 cents per ton per month after the first 30 days. Storage charges for the first 30 days are included in the charge of $0.75 to $1.25 per ton made for handling the grain. The grower who stores grain on the farm would be subject to this handling charge whenever he sold his crop. At these rates, commercial storage for the entire 1929 year would have cost $1.10 per ton or 3.3 cents per bushel, which is considerably cheaper than costs for farm storage on the farms studied. After the farm-storage plant is paid for, however, out-of-pocket expense for farm storage in a given year would probably be less than the cost of commercial storage.

Under normal conditions grain is seldom stored for a 12-month period. In storing commercially the grower would pay only for the actual time stored. The investment in farm storage must be borne for the full 12 months regardless of the period of actual use. The average farm on which farm-storage data were available produced 8,000 to 11,000 bushels of grain per year. Apparently considerably larger production is necessary before farm storage would cost less per bushel than commercial storage at the track.

TABLE 8.—*Estimated cost per bushel of farm storage on farms producing 8,000 to 11,000 bushels of grain in Washington, Oregon, and Idaho, 1929* [1]

Item	Level land	Hilly land
	Cents	*Cents*
Expense for year on farm storage plant [2]	1.10	1.10
Expense on gas engine for elevating grain (Table 6)	.18	.18
Expense for year on elevating device (Table 6)	.18	.18
Hauling with teams, combine to storage (Table 7)	2.17	2.78
Man to operate elevating device [3]	.61	.65
Total [4]	4.24	4.89

[1] Insurance on grain in farm storage would add a small amount to cost as shown.
[2] Weighted average cost of all stationary storage plants shown in Table 6.
[3] Wage used was 45 cents per hour including board.
[4] Commercial storage at the country shipping point would cost 10 cents per ton per month after the first 30 days. Such storage for the 1929 year would have cost $1.10 per ton or 3.3 cents per bushel as compared with cost given above.

Over much of the region studied weather conditions are such that ground storage of bulk grain might be used for short periods without great loss. An excerpt from a recent California study is of interest.

The storage problem is greatly simplified in this State, particularly for farmers just making the change in their handling method, by reason of the fact that it is practical for grain to be stored on the ground for as long as three months following harvest. Where hard, level ground is selected and cleaned of vegetation, there is no grain waste of consequence. The chances of loss from fire and moisture are practically eliminated in grain so stored. Even in the middle-western states where light summer showers are common, grain is stored temporarily on the ground without great loss. Some California farmers have practiced ground storage for the past few years and under their marketing plan of selling the grain during or immediately after harvest, it has been shown that temporary or emergency storage on the ground is practical. * * * Where grain is to be sold during or soon after harvest special farm storage structures, except for farm seed and feed, are of doubtful economy.[10]

HAULING DIRECT FROM FARM TO CAR

A few growers throughout the region are installing facilities at near-by sidings for loading out their own cars of grain. In most cases trucks bring the grain directly from the combine to the siding, where it is immediately loaded and shipped to market. Figure 23 illustrates one grower's track-loading equipment. The 250-bushel bin holds three to four truck loads of grain. Larger bins, such as that shown in Figure 24, provide better insurance against delaying combine operation in case the cars are not delivered to the siding in time. The main advantages in this practice lie in preserving the identity of high-quality grain, in reducing handling charges, and in a possible shortening of hauling distance if the farm is located near the railroad.

This attempt of the grower to perform his own marketing services may have the following disadvantages:

Terminal weights and grades must be accepted. Where grain is graded at the shipping point additional gradings by different parties may be resorted to if the first grade seems unsatisfactory. In most cases of track loading the grain is not weighed till the terminal is

[10] BAINER, R., and LONG, J. D. EQUIPMENT FOR THE BULK HANDLING OF GRAIN. Calif. Agr. Col. Ext. Circ. 47, p. [3]–4. 1930.

reached. This condition introduces the possibility of large losses should the car be wrecked and the grain lost in transit.

Although rail service is constantly improving there is a possibility of car shortages, especially in the later harvesting districts.

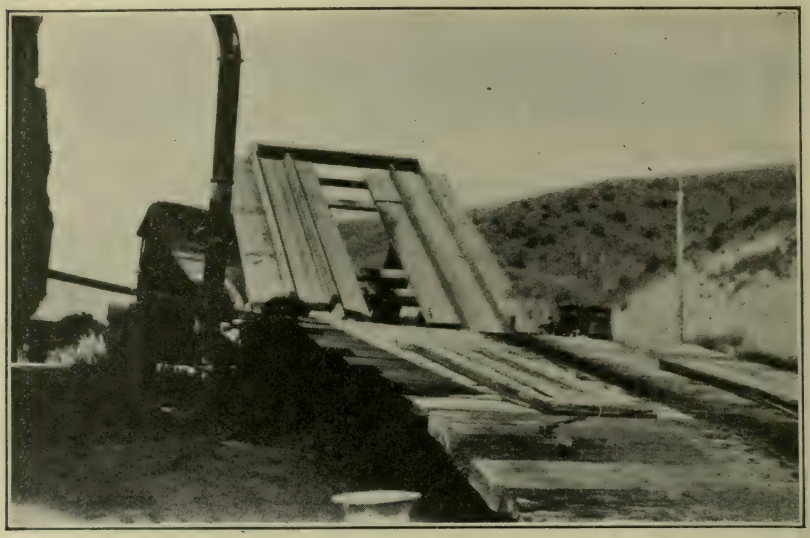

FIGURE 23.—Blowing grain into the car at a grower's track-loading plant. The truck runs up the incline to permit unloading by gravity from the end gate. Power for the blower is furnished by a belt take-off from the rear tire of a second-hand automobile that cost $50. The blower cost $162.50 and the 250-bushel hopper bottom bin cost $125

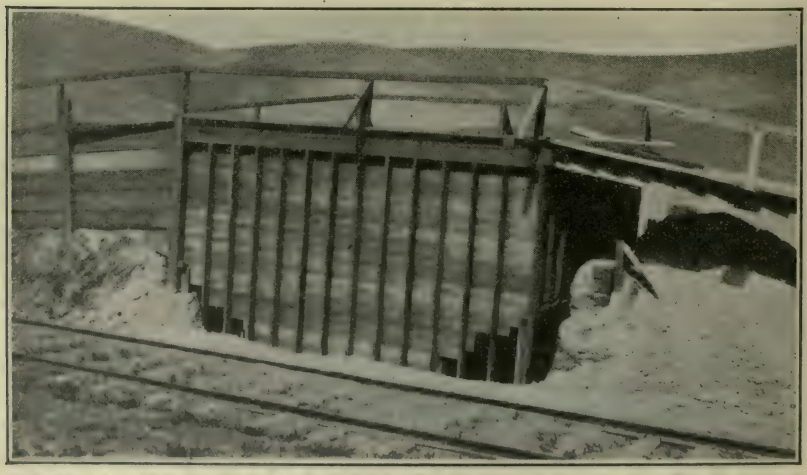

FIGURE 24.—A farmer's 1,500-bushel bin for track loading. The grain is hauled directly from the combine and put into the car by using a blower or elevating device. The bin is large enough to hold a day's cut if delivery of car is delayed. The gas engine and blower cost $161.50 and the bin cost $271

The practice promotes haphazard marketing and adds to the volume of grain that floods the terminals at harvest time, with a consequent temporary depressing effect on price.

Most growers who practice track loading have no farm-storage facilities; this means that they must sell at the time the bulk grain is harvested or place it in commercial storage. In the latter event the unused investment in track-loading facilities adds a double burden to handling costs for the year.

Grain loaded into cars by means of blowers is likely to be cracked and to be docked on that account. The cracking is usually not the fault of the blower but occurred because of the farmer's inexperience in setting up and operating the equipment.

Occasionally the practice of consigning track-loaded grain to dealers at terminal points, the usual practice, results in loss to the grower.

RETARDING INFLUENCES IN SHIFTING TO BULK HANDLING

The problem of bulk versus sack handling of grain is not new in the Pacific Northwest. In the past, interest in making the shift has increased and diminished with changing prices for sacks. Previous studies have indicated savings in handling grain in bulk from the time it leaves the combine until it is loaded on ships for export. The results of this study show farm savings of 3.8 to 4.7 cents per bushel where the grain is bulked directly from combine to shipping point. If such worth-while savings may be effected by shifting from sack to bulk handling why have growers been so slow in changing to the more efficient practice? A number of influences which have operated throughout the region to retard the shift are discussed in the following paragraphs.

CONVERTING SACKED TO BULK GRAIN BY "CUTTING-IN"

A considerable portion of the bulk grain loaded out at the shipping point is received at the country elevator in sacks. A grower who expects a crop of 2,000 sacks may purchase 500, which are filled four times during the season. The sacks are filled and emptied three times, and the grain is sold in bulk. The last time the sacks are filled they are not "cut-in" but are sold as sacked grain. The term "cutting-in" developed because the twine or wire with which the sack is sewed or tied is cut and the sacks are dumped for reuse. (Fig. 25.)

The number of times the sack is used varies from two to eight, three or four fillings being the most common. By cutting-in, the grower may sell bulk grain with no changes in organization of his harvest crew or equipment as used for sacking. The practice effectively reduces the sack cost, which is the most significant saving to be gained by bulk handling. No reduction in the drudgery of harvest work is gained by cutting-in. The practice tends to cause congestion at the country elevator, where bulk trucks are held in line while sacks are dumped.

Table 9 shows the influence of price of sack, number of times used, and whether it is sewed or tied on cost per bushel for the sack. Sack cost per bushel decreases with number of times the sack is used. Sewed sacks cost less per bushel than tied sacks, since approximately 25 pounds more grain is put in the sewed sack at each filling. Sixty-eight to eighty-five per cent of the saving effected on the farm by the

bulk method in 1929 was due to elimination of the expense for sacks. Savings in bulking are, therefore, largely dependent on the price of sacks from year to year. Although prices have fluctuated widely in the past, it seems reasonable to expect that a continuance of present prices or possible further reductions will discourage marked increases in bulk handling which would eventually eliminate the demand for sacks.

Under extremely hilly conditions, where considerable difficulty might be experienced in taking bulk grain from the combine with either trucks or teams, cutting-in in the field may be practiced. The grower purchases a small quantity of high-quality sacks which may be used for several years and the tied sacks are "cut" into bulk wagons or trucks before the grain is hauled to the elevator, thus relieving congestion at that point. The grower would need only to

FIGURE 25.—Bulking sacked grain at the country elevator by the "cutting-in" process. The same sacks are used several times during the season. Sack cost for the year is reduced, but the system is wasteful of man labor and causes congestion at elevator, as bulk trucks are held in line waiting to unload

purchase a few sacks and provide a bulk-grain box for the truck or wagon. This practice has the further advantage that the grain can be left in the sacks if at any time the elevator at the shipping point breaks down or is unable to handle the entire volume of bulk grain delivered to it.

WHEAT-VARIETY SITUATION

The number of varieties and classes of wheat grown in an area has considerable effect on the bulk-handling problem. If several classes are grown, more bins are needed in elevators to prevent mixing the grain. The cost of elevator construction and operation increases with the number of bins provided. In most elevators, varieties within a given class of wheat are dumped together, the main attempt being to keep classes and grades of wheat separate. Over half the wheat acreage in Washington, Oregon, and Idaho produces white wheats, over one-fourth hard red winter wheat, and the crop of most of the remainder is divided between soft red winter and hard red spring wheats.

TABLE 9.—*Factors influencing net cost per bushel for sack and twine in harvesting by sack and "cut-in" methods in Washington, Oregon, and Idaho*

Item	Sewed sacks used—				Tied sacks used—		
	Once	Twice	Three times	Four times	Twice	Three times	Four times
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Grain per sack [1]	2.25	4.50	6.75	9.00	4.08	5.92	7.75
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Cost, in 1929, of:							
Sack	13.50	13.50	13.50	13.50	13.50	13.50	13.50
Twine [2]	.50	1.00	1.50	2.00	1.00	1.50	2.00
Total	14.00	14.50	15.00	15.50	14.50	15.00	15.50
Premium on sacked grain [3]	6.75	6.75	6.75	6.75	6.75	6.75	6.75
Net cost of sack and twine, 1929	7.25	7.75	8.25	8.75	7.75	8.25	8.75
Net cost per bushel, 1929	3.22	1.72	1.22	.97	1.90	1.39	1.13
Net cost per bushel:							
When sacks cost 11 cents [4] as in 1930	2.11	1.17	.85	.69	1.29	.97	.81
When sacks cost 8 cents	.78	.50	.41	.36	.55	.46	.42
When sacks cost 20 cents	6.11	3.17	2.19	1.69	3.49	2.49	1.97

[1] Tied sacks estimated at 110 pounds of grain per sack; sewed sacks 135 pounds. "Cut-in" grain assumed to be sent out as sacked grain the last time sack is filled.

[2] If sacks are tied, same string might be saved and used over, thus reducing twine costs below those shown.

[3] A premium of 3 cents per bushel is paid for sacked wheat over the price of similar wheat in bulked condition. The amount of this premium is determined by the Pacific Northwest Grain Dealer's Association and is subject to some variation. It has remained at 3 cents per bushel for a number of years. For all "cut-in" grain the bulk price would be paid. On the last filling with the grain sold in the sack, the 3-cent differential on sacked grain would be allowed. Figuring 2.25 bushels per sack, this premium is 6.75 cents per sack.

[4] Average cost of a sack in this area in 1930.

The tendency toward standardization of varieties on the farms studied in the three States is shown in Table 10. Of the 97 Oregon growers interviewed, nearly one-half were growing but a single variety of wheat. Of 78 Idaho growers interviewed, slightly less than one-fifth were producing a single variety and over one-fourth were growing three varieties per farm.

The recognized varieties of wheat grown on the farms studied in each State are listed in Table 11. As the varieties grown vary considerably in different districts within each State, the varietal situation must be considered separately by each locality.

TABLE 10.—*Percentage of farmers interviewed who produced stated number of varieties of wheat, Washington, Oregon, and Idaho, 1929*

State	Farmers interviewed	Percentage producing—			
		One variety	Two varieties	Three varieties	Four or more varieties
	Number	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Washington	139	39	45	12	4
Oregon	97	46	48	6	----
Idaho	78	18	44	27	11

EFFECT OF TENANCY

A considerable part of the region studied is farmed by tenants. In some leases the tenant agrees to furnish sacks for the entire crop and to haul the landlord's grain to a shipping point. Under such an agreement the landlord naturally prefers his share of the crop in the sack since a premium of 3 cents a bushel is allowed for sacked grain over bulk grain of a similar grade.

TABLE 11.—*Variety and class of wheat grown by 262 farmers, Washington, Oregon, and Idaho, 1929*

Class and variety	Percentage of farmers growing the variety		
	Washington	Oregon	Idaho
Winter:	*Per cent*	*Per cent*	*Per cent*
Albit	29		7
Baart	17		
Pacific Bluestem	3		
Quality			3
Federation	27	62	51
Fortyfold	6	27	15
Hybrid 128 (club)	13	16	17
Hybrid 143 (club)			8
Jenkin (club)	9	6	22
White Odessa			3
Soft red winter:			
Jones Fife	9		
Red Russian			39
Triplet	24		8
Hard red winter:			
Mosida		2	7
Ridit	16		36
Turkey	29	43	
Hard red spring:			
Marquis	3		7
Red Bobs			10
Miscellaneous [1]	3	1	10
More than two, per farm	15.8	6.2	38.5
	Number	*Number*	*Number*
Farmers reporting	114	89	59

[1] Other varieties, each grown by less than 2 per cent of the group.

WAREHOUSE AND ELEVATOR FACILITIES AT SHIPPING POINT

Possibly the greatest single factor retarding the adoption of bulk-handling methods on the farm has been the lack of adequate storage and handling facilities for bulk grain at the country shipping point. Although a few country stations have adequate facilities, the greater part of the region has made little progress in developing such facilities.

The old-line grain companies which have served this region for many years have made investments in facilities for handling sacked grain. Naturally they hesitate to sacrifice these investments and provide bulk facilities at greatly increased costs.

Most of the earlier elevators were erected by farmer organizations. A number of these ventures proved unsuccessful, and some of the elevators are now operated by private interests which often purchased them at a considerable discount from the original cost.

Although investments in bulk facilities are much greater than those in sack handling (Table 12), competition for trade is such that rates for handling and storing bulked and sacked grain are usually the same at any country station. Many elevators are further handicapped because the grower stores his grain for long periods, thus preventing a greater turnover on elevator capacity. This condition has been changed in some localities by charging a second handling fee if grain is stored longer than 12 months.

Most of the concrete elevators were erected about 1918, but the investment per bushel of capacity (Table 12) is not greatly different from the investment that would obtain if the elevator had been built in 1930.

TABLE 12.—*Investment in bulk elevators and in sack warehouses for storing grain at the country shipping point in Washington, Oregon, and Idaho, 1929* [1]

Item	40 wooden elevators	19 concrete elevators	46 sack warehouses
Original cost of building and equipment.....dollars..	18,937.95	38,779.30	8,395.37
Capacity.....bushels..	65,602	88,947	102,224
Investment per bushel of capacity.....cents..	28.87	43.60	8.21

[1] Elevators averaged 13 years old and warehouses 21 years.

Lack of sufficient turnover would appear to be the greatest weakness in elevator operation in the Pacific Northwest. Table 13 shows the present relation of turnover to capacity and the effect on investment per bushel handled if greater volumes of grain were cared for each

FIGURE 26.—Farmers' cooperative elevator at a country shipping point. Facilities are provided for handling both sack and bulk grain. Scarcity of such facilities in the Pacific Northwest tends to retard the shift to bulk handling on the farm

season. The experience of many operators here and in Canada would indicate that, for a safe margin of profit, an elevator should handle a minimum of three times its capacity. Several of the more successful growers' elevators (fig. 26) do not depend entirely on quantity of grain handled for revenue. The grain is cleaned and skillfully mixed, thus raising its grade before it is sold.

TABLE 13.—*Effect of quantity of grain handled on the investment in elevators at country shipping point in Washington, Oregon, and Idaho*

Item	29 wooden elevators	14 concrete elevators
Original cost of building and equipment.....dollars..	19,980.17	39,916.91
Capacity.....bushels..	66,244	92,143
Grain handled per season.....do....	100,462	122,679
Turnover in terms of capacity.....number..	1.52	1.33
Investment per bushel of capacity.....cents..	30.16	43.32
Investment per bushel handled.....do....	19.89	32.54
Investment per bushel handled if turnover had been three times the capacity.....cents..	10.05	14.44

Data obtained during 1930 from contractors in the region indicate the following range in investments per bushel of capacity for the various types of grain-handling facilities:

	Investment per bushel of capacity, cents
Bulk-handling facilities:	
Concrete elevators, fully equipped	40 to 50
Wooden elevators (crib construction), fully equipped	25 to 35
Converted flat warehouses, fully equipped in addition to original investment in flat warehouse	8 to 13
Sack-handling facilities: Flat warehouse fully equipped (figs. 27 and 28)	9 to 14

CONVERSION OF SACK WAREHOUSES

A limited number of flat warehouses have been converted to handle bulk grain in the region studied. Bulk-handling facilities are thus provided at low cost, and the investment in sack warehouses is

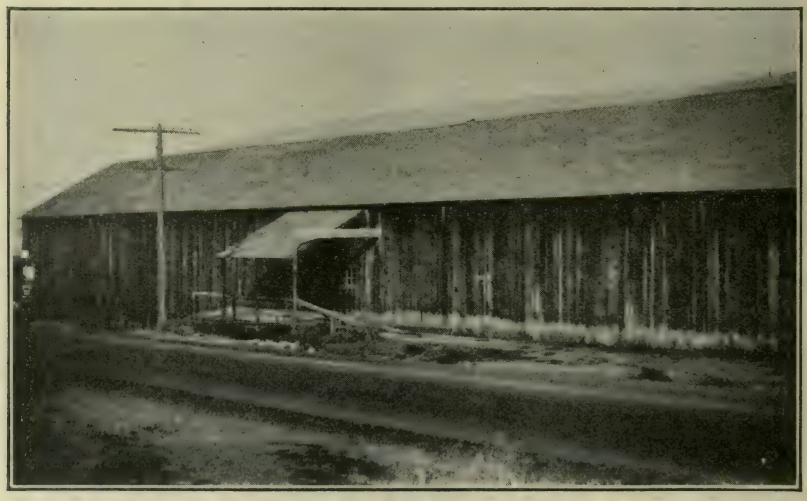

FIGURE 27.—A typical warehouse for storing sacked grain at a country shipping point in the Pacific Northwest. Cheaply but sturdily constructed at an average investment of 9 to 14 cents per bushel for 100,000-bushel capacity

utilized rather than sacrificed. Bins are constructed of 2 by 4 inch and 2 by 6 inch material on the floor of the old sack house. Delivery of grain to the horizontal row of bins is accomplished by augers or by a gravity system. (Fig. 29.) Earlier attempts at this type of construction were not wholly satisfactory. The concentration of great weight on a limited amount of floor space caused the floors to settle. This in turn caused shafting and conveyor systems to get out of line and bind, giving considerable trouble. Cribbing in the bins spread apart and grain leaks developed. Extensive repairs had to be made to the foundations to remedy these defects.

By properly reinforcing foundations with concrete, by mounting shafting and conveyor systems on independent foundations to permit settling of the floor without damage to them, and by tie-rodding and reinforcing bins, much more satisfactory results have been obtained in houses converted more recently.

Experience with this type of bulk facility in California is summarized as follows:

Structurally sound sack warehouses may be converted into storages for bulk grain but the few instances in which this has been done in California have not proven entirely successful. A great deal of attention must be directed toward securing the proper design and construction; remodeling should be undertaken only after mature deliberation and consideration of the salvage value of the warehouse for other purposes.

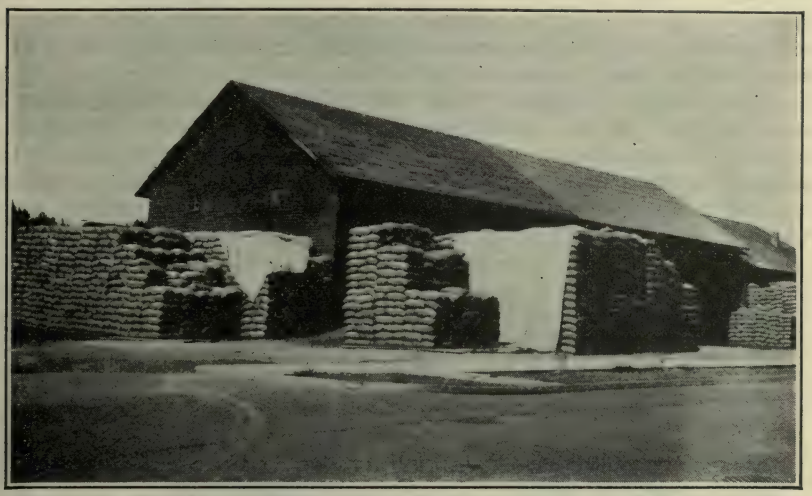

FIGURE 28.—Sacked grain piled outside after the warehouse was filled to capacity. Grain in sacks lends itself readily to such temporary-storage measures

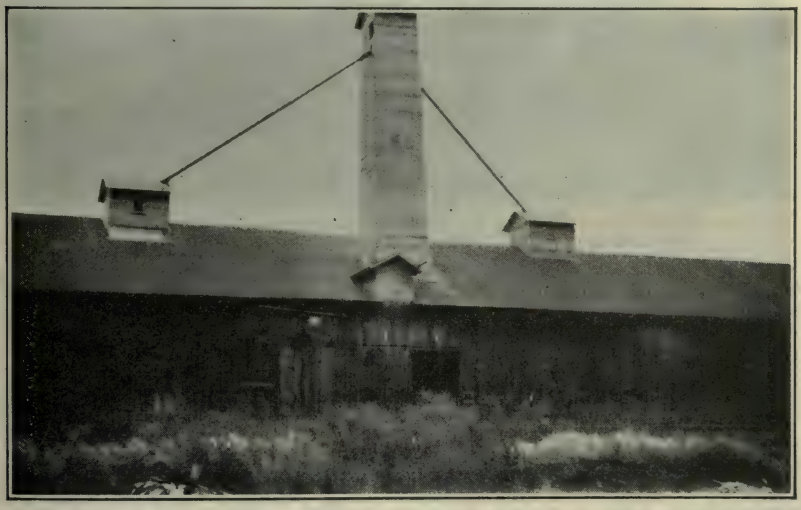

FIGURE 29.—A sack warehouse converted to handle bulk grain. Bulk facilities were provided by adding 8 to 13 cents per bushel to the investment. The high elevator leg permits gravity distribution to individual bins

In the instances where warehouses have been remodeled the costs have been practically as great as for new construction and the facilities provided inferior.[11]

Those who contemplate the conversion of sack houses would do well to visit plants already converted to obtain a first-hand knowledge of the possibilities and the construction problems involved.

[11] BAINER, R., and LONG, J. D. Op. cit., p. 6–7.

FACILITIES FOR HANDLING BULK GRAIN AT TERMINAL POINTS

The total capacity for storage of bulk grain at terminal points in Washington and Oregon is slightly less than 13,000,000 bushels. (Table 14.) Receipts of all wheat in 1927 (the year of heaviest receipts in the 1923–1929 period), were over six times this bulk capacity. Over half the available bulk space is in private storage; it is owned by mills that process the grain by converting much of it into flour and feed before it enters trade channels. (Fig. 30.) This tends to reduce the speed with which private bulk storage can be emptied and refilled. Temporary shortages in bulk facilities at these terminal points have already been experienced. With but few bulk elevators at country shipping points and still fewer available farm-storage plants, it would seem possible to overtax present terminal facilities for handling the bulk grain of this region should a rapid change to bulk handling take place on the farm.

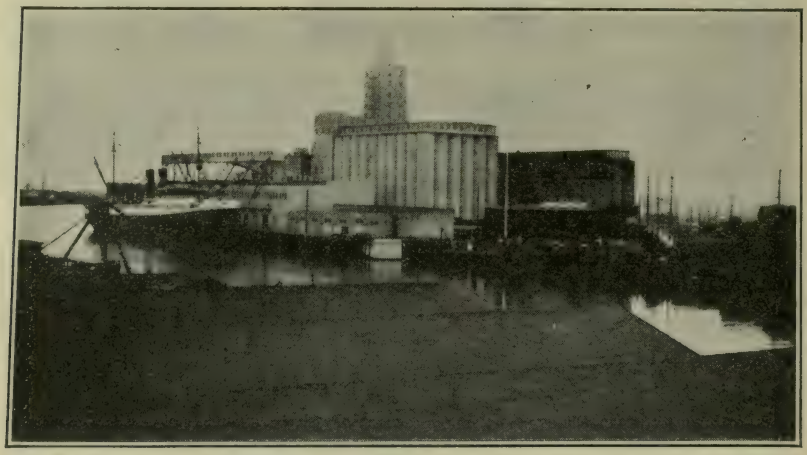

FIGURE 30.—A large terminal elevator on the Pacific coast, equipped to handle bulk and sack grain. Both flour and whole grains are exported

TABLE 14.—*Storage capacity for bulk and sack grain at terminal points in Washington and Oregon, 1930*[1]

Location	Private storage		Public storage		All storage		Total capacity bulk and sack
	Bulk	Sack	Bulk	Sack	Bulk	Sack	
	1,000 bushels	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*
Seattle, Wash.	2,895	555	1,867	3,250	4,762	3,805	8,567
Portland, Oreg.	2,331	2,275	2,000	1,000	4,331	3,275	7,606
Astoria, Oreg.			1,200	1,000	1,200	1,000	2,200
Tacoma, Wash.	1,525		650		2,175		2,175
Longview, Wash.			385	15	385	15	400
Total	6,751	2,830	6,102	5,265	12,853	8,095	20,948

[1] Compiled from the following: SCHOENFELD, W. A., and DENNEE, J. S. A COMPENDIUM OF WHEAT STATISTICS (OF INTEREST TO THE PACIFIC NORTHWEST). 162 p. Seattle, Wash. 1929. [Mimeographed.] (Figures brought up to date for 1930.)

GENERAL CONCLUSIONS

Possibly the greatest appeal that bulk handling makes to the grain grower is its elimination of the ardous labor involved in handling grain in sacks. In observing the harvest operations of neighboring farmers who are bulking their grain, the difference in expenditure of physical energy is obvious.

When times are hard and every effort is being made to reduce cash outlay, savings by the bulk method in eliminating the sizable bill for sacks also prove highly attractive.

With normal conditions of yield, savings in the cost of man labor when bulking grain are of considerable significance. The importance of this factor varies from farm to farm and from year to year. When yields are light, the size of combine crews is reduced whether they operate sack or bulk combines. Under some organizations the number of men necessary, at a given time, for handling grain in bulk may equal or exceed the number used for operating sack combines of the same size. This is because of the necessity of maintaining a hauling crew working in conjunction with the operation of the bulk combine. Under sack-handling methods the hauling operation is entirely independent, and part of the combine crew is often utilized to haul the sacked grain after the rush work is completed. On the other hand, the bulk-handling system frequently permits those members of the family who lack the physical requirements for handling sacks, to replace the robust hired hands necessary when sack-harvesting methods are used. Although yields vary from year to year and the amount of available family labor is not a constant factor, it is safe to assume that the entire cost of man labor, as well as out-of-pocket expense for this item, will in most instances be less when the grain is handled in bulk.

Shifting to bulk handling is very much easier, and greater savings result, where the land is level or only gently rolling. Corroborative of the efficacy of the bulk-handling system under favorable ground conditions is its widespread use in the comparatively level wheat-producing areas of the Middle West.

Large areas of wheat land in the Pacific Northwest are very rolling; here the conversion to bulk handling presents some very difficult problems. A considerable number of growers have surmounted these difficulties and have developed satisfactory bulk-handling equipment on their farms. It may be said, however, that smaller savings have resulted where growers in hilly regions have shifted from sack to bulk handling than where the shift has been made by growers with farms on level land.

Although bulk-handling equipment is still in the process of experimentation, some progress is being made in the development of equipment satisfactory for use on steep slopes. Steep slopes with light porous soils present the most difficult problem. Under such conditions the bulk combine tends to cut deeply into the soil, presenting draft and traction problems that are not easily overcome. Combine wheels may need to be widened, additional horses or larger tractors may be required, and it may be necessary to lighten loads of grain in the bulk tank. Where slopes are extremely steep additional in-

vestments in equipment and added labor expense are incurred in transferring the grain from combine to trucks for the haul to the shipping point. Before investing, growers who operate where slopes are steep and who plan to shift to bulk handling should assure themselves that the contemplated equipment is adapted to their own conditions.

Bulk-handling machinery for use on level land has long since passed through the experimental stage and reached the point at which satisfactory performance may be expected from most equipment offered for sale.

If grain is bulked directly from combine to shipping point, little outlay is necessary in converting sack equipment into bulk equipment. With the present meager facilities for storing and handling grain in bulk at most country shipping points, however, relatively few growers can enjoy this simple organization without quickly overtaxing their shipping facilities. Any sizable volume of bulk grain delivered to small country elevators must be immediately loaded out and shipped to market to make room in the elevator for new supplies as they arrive from the farm. This practice tends to produce temporary gluts at terminal points and a consequent depressing effect on price.

It seems apparent that adequate facilities for storing and handling bulk grain must be developed at the country shipping point or growers must erect their own farm-storage plants. It has been shown that farm storage is more expensive for the grower on the average-sized farm than is storage at commercial rates at the country shipping point. It has been demonstrated that the investment in the farm-storage plant, with its attendant upkeep expense and the extra labor involved in additional handlings of the grain, materially reduces, and in some cases eliminates, savings that might otherwise accrue with the bulk-handling method. The inability to obtain loans on farm-stored grain and the lack of an entirely adequate system of improved roads that would permit delivery of grain at any season of the year, are factors still further discouraging farm storage.

Probably the most plausible solution of the problem lies in the erection of adequate bulk-handling facilities at the country shipping point. The grain trade through the entire region has made its investments primarily in warehouses and equipment for handling sacked grain. To relinquish a profitable business in the sale and handling of sacks and, in addition, provide much more expensive facilities for handling grain in bulk in order that the grower may follow a more efficient method of handling grain on the farm, would be expensive for the trade. In a few areas where growers have largely shifted to bulk handling, established dealers have found it necessary to provide bulk-handling facilities in order to keep their trade. Such pressure, however, will not exist until the majority of growers in any community have made the shift. It seems more probable that such construction will be delayed until growers are financially able to erect facilities by cooperative effort.

An ultimate shift to bulk handling over much of this region is desirable and may be expected, but the change should proceed cautiously, care being exercised to coordinate the movement so that bulk-handling facilities at country shipping points and terminal

markets shall keep pace with increasing volumes of bulk grain received from the farm.

SUMMARY

Though grain is now shipped in bulk from terminal points in Washington and Oregon, over 60 per cent of the wheat crop of 1929 received at Columbia River and Puget Sound terminals arrived in sacks. This study sought to determine the relative economy of bulk and sack handling methods under prevailing conditions by assembling the experience of 316 growers and other available information.

Man-labor cost of combine operation was less under the bulk-handling method than under the sack-handling method. On an average the labor saving amounted to 1.6 cents per bushel in 1929. Sack handling usually requires one or two more men per crew. The bulk-handling method requires less physical exertion so that boys of the family and men beyond their prime may do the work and save part of the out-of-pocket expense incurred if hired help were needed for the heavier work involved in sack handling.

Hauling grain in bulk is *easier* but not *cheaper* than hauling sacked grain. Comparable figures for short hauls in owned trucks were 2.84 cents per bushel for sacked grain and 3.03 cents per bushel for bulk grain. The advantage gained in ease of loading and unloading is lost in most cases in the tending operation. Contract hauling cost somewhat more per unit per mile except for short hauls of sacked grain. Losses of grain were considered by growers who had used both methods to be greater in sack handling than in bulk harvesting. Significant delays were encountered in harvesting operations relatively more often by farmers harvesting with bulk equipment than by those harvesting with sack equipment, and the average time lost by those reporting time lost was larger.

Four times as much labor is needed to load a 40-ton car with sacked grain as is needed to load bulk grain.

Cost of converting sack-harvesting equipment to bulk handling ranged upward from $150. A bulk tank is needed for the combine and a tight truck box instead of the flat platform used on the truck in hauling sacked wheat. Many ingenious means of surmounting local difficulties were found. Few growers who have shifted have actually discarded their sacking equipment. Adequate facilities for farm storage, where that is needed as part of the bulk-handling program, involve investment of about 20 cents or more per bushel of capacity. On the farms studied farm storage of bulk grain cost more per bushel (4.24 cents in level land sections) than commercial storage (3.3 cents). Only 47 per cent of those who were bulking their grain were equipped with stationary farm-storage plants.

Cost of hauling bulk grain from combine to farm storage was nearly as great as the cost of hauling from combine to shipping point. Bulk handling saves the grower the cost of sacks, which in 1929 amounted to 3.22 cents per bushel and constituted the greatest dollar-and-cents saving. In 1930 sacks cost 2½ cents less than in 1929, so the saving was smaller. Growers who use sacks more than once in a season by "cutting-in" their grain at the shipping point one or more times can reduce the net cost of sacks per bushel to a small

figure. " Cutting-in " does not reduce the drudgery of harvest work, however, and sometimes causes congestion at the country elevator.

Wheat of more than 18 varieties in four classes was grown on the farms visited. If several classes are grown, more bins are needed in elevators to prevent mixing. The cost of elevator construction and operation increases with the number of bins provided. The varietal situation in its effect on bulk handling must be considered in each locality.

Lack of adequate storage and handling facilities for bulk grain at the country shipping point has been the greatest single factor retarding the adoption of bulk-handling methods on the farm. Investments are necessarily heavier, but competition is such that rates charged at any station are about the same for bulk as for sacked grain. Turnover is small (1.33 to 1.52 times capacity), a serious weakness in elevator operation. Some sack warehouses have been converted to handle bulk grain, with results suggestive of need for full consideration of all factors of the problem by those who contemplate such conversion.

Terminal storage facilities for bulk grain in Washington and Oregon had in 1930 a rated capacity of nearly 13,000,000 bushels. Receipts of wheat in 1927 were over six times this bulk capacity. Temporary shortages of bulk facilities have already been experienced.

An ultimate shift to bulk handling over much of the Pacific Northwest is desirable and may be expected, but the change should be made cautiously. Costly mistakes in selection of equipment, especially in the more hilly areas are to be avoided, and care is needed to coordinate the movement so that bulk-handling facilities at country shipping points and terminal markets shall keep pace with increasing volumes of bulk grain received from the farms.

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TECHNICAL BULLETIN No. 286 APRIL, 1932

DECAY AND OTHER LOSSES IN DOUGLAS FIR IN WESTERN OREGON AND WASHINGTON

BY

J. S. BOYCE

Principal Pathologist
Division of Forest Pathology
Bureau of Plant Industry

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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INTRODUCTION

Douglas fir, *Pseudotsuga taxifolia* (Lamb.) Britton, is the most important timber tree in the Pacific Northwest and, owing to ease of reproduction, rapidity of growth, and simplicity of management, will undoubtedly continue to hold a commanding position. In recognition of the fact that the species is necessary to the economic future of the region in which it attains optimum development—that is, in western Oregon and Washington west of the summit of the Cascade Mountains and north of the divide between the Umpqua and Rogue Rivers—and that it is extremely valuable to the country as a whole, investigations have been concentrated on its life history and habits, in order to provide a sound basis for its management.

Hofmann (*12*) [1] has studied the regeneration of Douglas fir. Munger (*24*) has outlined the procedure necessary to perpetuate timber production. Munger, years ago (*22*), and later McArdle (*15*) presented facts on the yield of younger stands up to 160 years of age. But since all stands suffer loss from breakage when the timber is felled, from shake, waste, fire, fungi, insects, or other cause, knowledge of prospective yield is of value only if correlated with knowledge of prospective loss and, while a clear understanding of the relative importance of the factors causing loss is needful, information on which the possible rate of loss throughout the life of the stand can be predicted is even more essential, since it is axiomatic

[1] Italic numbers in parentheses refer to Literature Cited, p. 58.

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that loss increases with age. Consequently, for proper management and intelligent handling of Douglas fir in the future it is necessary to know not only the loss in second-growth stands up to 160 years old but also to have reasonably exact knowledge of the rate of deterioration of overmature stands. Although it is true that overmature stands, except when reserved in parks or when completely inaccessible, will disappear in the ultimate future, at present they cover large areas in this region, so that cutting in them will continue for some decades. Meanwhile the approximate rate at which such stands are deteriorating is of primary importance to owners of this class of timber.

Living Douglas fir in the region referred to is very little affected by insects, fungi (except heartwood destroyers), and mistletoe. The Douglas-fir bark beetle, *Dendroctonus pseudotsugae* Hopk., is everywhere present in felled trees, but so far has caused no important losses in living timber. A woolly aphid, *Chermes cooleyi* Gill., on the needles, is widespread but relatively harmless. Periodically the western-hemlock looper, *Ellopia fervidaria* Hbn., becomes epidemic and destroys considerable merchantable timber over localized areas before it subsides. The needle-cast fungus, *Rhabdocline pseudotsugae* Sydow, is locally prevalent, and during seasons favorable for its development may cause much defoliation. It usually confines itself to trees in the seedling, sapling, and small-pole stages and is decidedly selective in its action, rarely attacking an entire stand but appearing on a greater or lesser number of scattered individuals. A particularly susceptible tree may repeatedly be defoliated so that it finally becomes badly suppressed and has strikingly shortened needles and an unhealthy yellow-green color. The inconspicuous and relatively harmless needle-rust fungus, *Melampsora albertensis* Arth., has not been found in the region. Seedlings and saplings are occasionally killed by the honey fungus, *Armillaria mellea* (Vahl) Fr., and it is probable that in the future, when planting of Douglas fir is more extensively carried on, this root rot will become increasingly serious. The conifer root fungus, *Fomes annosus* (Fr.) Cke., which frequently kills young Douglas firs in Europe, has not been found as a parasite in this region, although it occurs occasionally on old stumps, logs, and down trees. Douglas dwarf mistletoe, *Razoumofskya douglasii* (Engelm.) Kuntze, so destructive to Douglas fir throughout much of its range, and particularly in Oregon and Washington on the east slope of the Cascade Mountains, is unknown west of the summit of the range except in southern Oregon. For example, in the Hood River Valley, which lies east of the summit, the mistletoe is common. From this valley through the Columbia River Gorge has stretched an unbroken belt of Douglas fir extending practically to the Pacific Ocean. Yet the mistletoe has not followed through with its host. Neither has it followed through from southern Oregon to north of the divide between the Umpqua and Rogue Rivers. Climatically, the region with its high rainfall and cloudy weather in contrast to the much drier, more sunshiny weather east of the summit is not unfavorable to the dwarf mistletoes as a group, for hemlock dwarf mistletoe, *R. tsugensis* Rosend., is common on western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and fir dwarf mistletoe, *R. abietina* (Engelm.)

Abrams, is occasionally met with on lowland white fir, *Abies grandis* Lindl. The factors limiting the distribution of the mistletoe on Douglas fir present an interesting and unsolved problem.

What is most to be feared, however, is the introduction of some foreign insect or fungous parasite, which, freed from its natural enemies and finding itself adapted to the moderate temperatures and high precipitation characterizing the region, will become epidemic and destructive throughout the thousands of square miles of almost pure stands of Douglas fir.

Douglas fir is also affected by a form of winter injury known as parch blight (*23*). During the winter months, which are characterized by long periods of rainy and cloudy weather, with westerly winds and moderate temperatures, sudden changes occur, and usually, once or twice a winter for periods of a few days to a week or more, cold, clear weather prevails, accompanied by very dry easterly winds from east of the Cascade Mountains. Almost immediately the foliage on the Douglas firs turns reddish brown, and the stands affected, those on the east slopes or ridge tops being especially susceptible, present a "scorched" appearance. Often the injury, if not severe, passes unnoticed until spring. While the parch blight is alarming in appearance, the trees rarely suffer serious effects, and by the end of the next growing season at the latest, signs of the injury have practically disappeared. Parch blight is particularly prevalent in the low passes through the mountains, such as the Columbia River Gorge and Snoqualmie Pass. In these locations the trees, owing to repeated injury, often have thinner foliage, shorter branches, and more dead branches on their east sides.

Young stands are sometimes severely damaged by ice storms, locally known as "silver thaws" or by wet-snow storms. The heavy load of snow or ice breaks off the tops of the trees, and a severe storm may injure the majority of the trees in a stand. This condition is shown in Figure 1. The missing top of a damaged tree is replaced by a limb which then becomes a "volunteer" top; but the crook in the trunk, at the point where the original top broke off and the limb replaced it, finally disappears only after decades. Furthermore, the broken top, while it slowly heals over, is an entrance point for wood-destroying fungi.

But the foregoing causes of loss, although they must be recognized, do not result in an alarming reduction in the volume of stands. However, the principal impression made by the older Douglas fir forests is of great density and enormous gross volume per unit of area and then of the enormous loss from decay indicated by conks on the living trees, and, to the initiated, by other signs. A visit to a logging operation and a sight of the large amount of slash left on the ground confirms the impression. Because of the seriousness of the decay in Douglas fir, a thorough investigation was begun in 1917. The results of one intensive study of the decay in relation to individual trees have been published (*4*), but the concluding paragraphs of that paper show that the author realized that this was only a preliminary study which would have to be followed by a more intensive investigation into the relation of decay to stands. These paragraphs were as follows:

> The biggest problems remain unsolved. Our half-formulated ideas of control of decay in Douglas fir are based on observation without a sound backing

of exact data. Furthermore, while it is a well-established fact that young stands or second growth are relatively immune from decay, it is not yet determined at what age in the life of the stand this immunity ceases and the trees become subject to extensive decay. Establishing this age will enable us in the future to cut stands before there is any real loss and at the same time permit the trees to attain the maximum size.

Equally important is the periodic rate of increase in the loss through decay after the above age has been passed. Such information is of the highest value

FIGURE 1.—Douglas firs with the tops broken off by a severe ice storm. Most of this young stand had been killed by fire before the picture was taken

to organizations holding extensive stands of mature or overmature timber, enabling them to estimate the loss in their holdings and adapt plans accordingly. But these questions can only be answered by a study of all the trees felled and left standing on a wide range of plots in stands of different ages and conditions selected on logging operations throughout the Douglas fir region of the Pacific Northwest.

The purpose of the present study was to solve as far as possible the problems outlined in these paragraphs.

METHOD OF STUDY

Since it is known (*22*) that second-growth Douglas fir up to 140 years old is essentially even aged, it was assumed that stands would remain so throughout their life; consequently, in order that this study of decay might be of the greatest value it was for the most part based on all the trees on an area, and these areas, whatever their size, were resolved to acre plots. In other words, fundamentally the study should follow the same general method as the yield study for this species (*15*) already completed. Naturally, since it was necessary to make the study on felled and bucked timber in order to evaluate decay correctly, it was not feasible, owing to the exigencies of logging operations, to lay out acre plots or strips. In fact, during the four field seasons, from 1921 to 1924, in which the field data were collected by a party of three men,[2] it was frequently difficult to find felled and bucked timber of the needed age classes. Furthermore, measuring felled and bucked timber consumes much time, so that it was possible to obtain data on only a small number of plots as compared with the number used in a yield study in which standing timber alone is measured, since standing timber can be measured very rapidly.

In measuring the trees the average height of the stump was taken. On slopes this point of measurement was halfway between the upper and lower sides of the stump. The first log was measured at 16.3 feet above the stump height to reduce as much as possible the error in figuring cubic volume caused by the butt swell. Beyond this the logs were measured where bucked or broken, except that in accordance with the United States Forest Service practice in this region, which does not permit the scaling of a single log more than 32 feet in length, longer logs were divided into equal parts to the nearest 2 feet. A 40-foot log, for example, was considered as two 20-foot logs, while a 42-foot log would be measured as a 20 and a 22. These measurements were carried to a fixed diameter limit of 8 inches inside the bark, while beyond this the bole was considered too small to be merchantable and classed as top, one lineal measurement being taken. Many trees had portions of their tops missing, broken up and lost in the general accumulation of débris incident to felling. A set of taper curves, arranged by 2-inch diameter breast high and 20-foot height classes, based on 912 trees on which complete lineal measurements were obtained, was used to complete the measurements on such trees. Where the logs were bucked or broken the average diameter inside the bark and the average width of bark were determined at each log length, while measurements were made on decay and other defects and descriptive notes taken. Where there was no buck or break, only diameter inside the bark and bark width were taken at log lengths necessitated by the rule against measuring logs longer than 32 feet. All measurements were recorded to the nearest tenth. The age of

[2] Acknowledgment is made of the assistance of E. G. Mason, of the School of Forestry, Oregon State Agricultural College, N. Leroy Cary, and P. E. Melis, who were in charge of the field party at various times. Acknowledgment is also made to the Pacific Northwest Forest Experiment Station for the site curves for the younger stands and the extension of these curves for older stands, made expressly for this study, and to L. H. Reineke, of the U. S. Forest Service, for valuable assistance in drawing the curves presented in this bulletin.

each tree was determined at stump height, and the few years additional needed to increase this to the age at ground level were read from an age-height curve for seedlings and small saplings.

The entire tree from ground level to tip was included in the computation of volume in cubic feet, the stump being treated as a

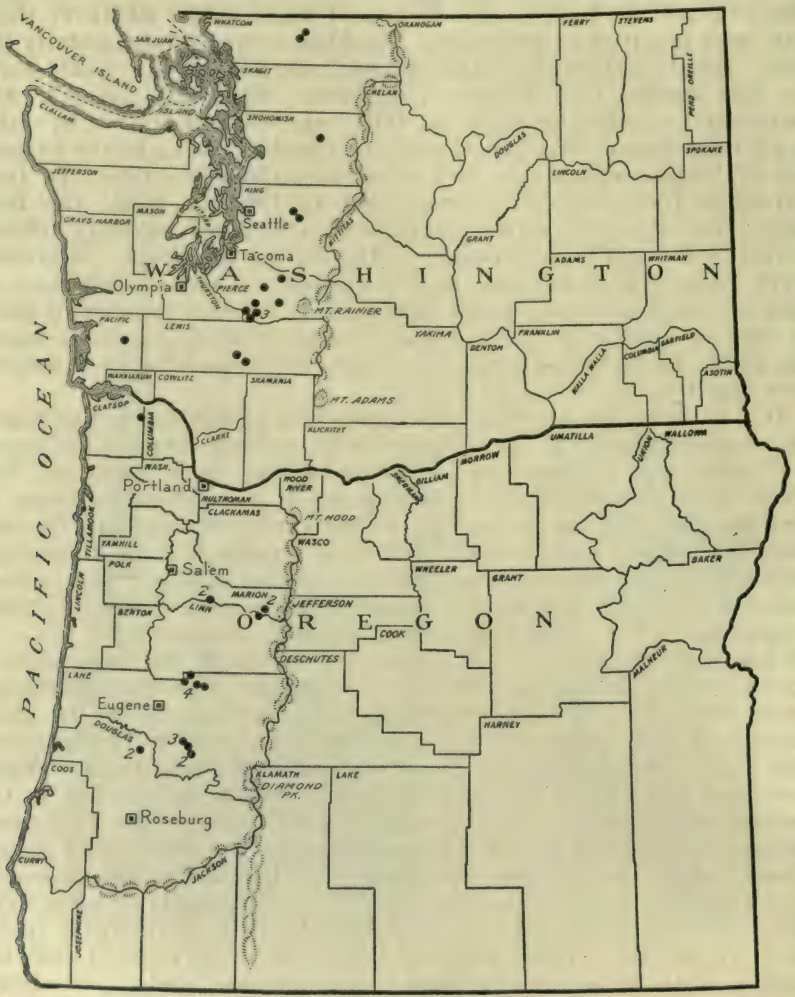

FIGURE 2.—Location of plots in western Oregon and Washington. Each dot represents the approximate location of one or more plots

cylinder, each log as the frustum of a paraboloid and the Smalian formula[3] applied, and the top as a cone. In "stagheaded" trees from which the tops had been broken off previous to felling, the section beyond 8 inches diameter inside the bark was treated as a frustum of a paraboloid instead of as the frustum of a cone, since

[3] $(B+b)\frac{h}{2}$, in which B = basal area of the large end of the log in square feet, b = basal area of the small end in square feet, and h = length of the log in feet.

it was found that the slight increase in volume given by the first formula was a negligible difference based on the total volume of the tree, and volumes were more quickly computed by the first formula than by the formula for the frustum of a cone. In determining the board-foot volumes of the trees, that portion of the bole lying between stump height and a fixed top-diameter limit of 8 inches inside the bark was considered as merchantable. The logs were measured in board feet by the Scribner Decimal C Rule.

Measurements were made of 2,633 Douglas firs with a volume of 10,146,530 board feet and 1,571,368 cubic feet on 38 plots covering 77.79 acres. The approximate location of these plots is shown in Figure 2. Where several plots were measured in the same locality, a figure with the black circle indicates the number. Basic data are given in Table 1, in which the individual plots are grouped by site classes and then arranged by average age, beginning with the youngest plot in each site class.

TABLE 1.—*Basic data on Douglas firs of merchantable size by plots*

Plot No.	Area	Site		Average age	Average diameter breast high	Average height	Gross volume per acre in—				Trees (basis)
		Class	Index				Board feet	Percentage of entire stand	Cubic feet	Percentage of entire stand	
1	2	3	4	5	6	7	8	9	10	11	12
	Acres			*Years*	*Inches*	*Feet*					*Number*
15	3.00	I	188	204	34.8	207.6	150,990	93.5	24,078	92.4	164
10	2.85	I	192	232	42.9	217.1	192,960	87.0	29,379	86.1	125
18	4.63	I	190	333	80.6	227.9	133,740	89.3	19,572	89.3	44
21	2.02	I	205	340	50.0	246.6	222,760	97.2	32,801	96.4	60
28	2.31	I	198	412	74.0	254.9	294,870	94.4	43,684	93.0	52
11	1.34	II	178	64	16.7	135.9	40,260	86.8	8,317	85.4	129
32	2.86	II	155	94	24.5	136.7	51,030	94.4	9,625	92.8	167
6	1.35	II	171	112	31.0	170.5	92,730	94.9	15,431	93.7	71
33	2.06	II	176	122	32.2	175.3	81,400	90.6	13,304	88.3	78
8	2.30	II	178	158	39.7	190.0	124,820	97.6	20,287	96.7	97
26	2.10	II	174	183	44.9	190.0	120,480	99.9	19,560	99.8	72
14	.78	II	182	197	33.5	208.1	177,190	99.5	27,863	99.2	52
7	1.24	II	175	198	53.9	203.6	154,110	99.1	23,956	98.8	34
12	2.35	II	181	237	39.6	209.3	180,350	94.1	27,502	92.1	108
16	2.16	II	182	238	40.5	212.3	109,170	99.4	17,234	99.1	65
27	.91	II	178	243	40.5	207.0	165,020	99.5	25,673	99.0	44
25	3.66	II	182	245	51.9	213.0	162,100	99.9	24,868	99.9	93
35	.59	II	168	245	33.7	190.8	99,730	96.8	16,253	95.1	26
17	1.13	II	180	245	38.0	199.6	126,110	90.8	19,694	87.8	44
36	1.18	II	157	258	42.4	172.3	125,230	96.1	19,197	94.4	38
30	1.16	II	174	289	44.9	206.2	229,140	95.0	35,158	93.6	62
24	1.09	II	170	309	41.9	205.3	227,110	99.6	34,567	99.5	59
22	1.58	II	174	316	47.4	211.0	127,140	94.7	19,335	92.8	36
38	2.38	II	180	319	53.5	224.8	161,270	99.9	23,705	99.9	51
37	2.23	II	174	322	59.0	216.5	149,150	100.0	21,790	100.0	38
31	1.68	II	179	333	47.1	221.7	231,680	94.4	35,828	93.4	79
13	1.15	II	183	345	57.6	238.4	237,620	95.3	35,192	93.9	32
20	2.00	II	183	349	51.5	223.3	253,400	99.7	38,161	99.6	79
34	3.00	II	169	383	63.5	211.0	85,800	92.7	13,051	89.4	28
23	2.33	II	174	404	59.5	214.6	177,300	96.1	26,252	94.9	48
19	1.96	II	164	559	83.5	212.5	113,610	72.7	16,879	68.4	13
4	1.02	III	150	66	18.8	119.9	17,750	58.6	3,759	58.5	37
1	2.86	III	144	103	24.5	122.6	34,820	89.5	5,695	87.7	48
2	2.00	III	150	114	29.6	147.0	47,390	91.8	8,477	89.8	62
5	2.71	III	142	116	25.9	134.4	36,780	82.1	7,037	80.9	117
29	1.00	III	143	145	24.3	145.0	68,410	99.5	12,809	99.2	82
3	3.41	III	130	149	29.1	142.6	39,980	79.9	7,024	77.1	88
9	3.41	III	132	400	36.4	168.1	78,650	97.1	12,722	95.7	111
Total or average	77.79			221							2,633

All computations were carried to two decimal places; but the resulting figures were rounded off to the nearest tenth, unit, or, in the case of board feet, 10, for this and subsequent tables, which explains minor discrepancies that may appear between the actual average or addition of figures cited and the figure for such average or addition recorded in these tables.

Naturally, stands on different areas will have different yields at the same age because of differences in soil, altitude, exposure, temperature, precipitation, and other physical factors, all of which influence productivity. Site class or site quality expresses the relative productive capacity or quality of different areas resulting from the action of the physical factors. The most reliable expression of site quality has been found to be the average total height of the dominant and codominant trees; that is, the largest and usually the tallest trees. In this region five classes of sites are recognized for Douglas fir, designated as excellent, good, fair, poor, and very poor, or for convenience as I, II, III, IV, and V. McArdle (*15*) discusses site for Douglas fir in some detail.

In column 3 of Table 1 the site class of each plot is given. The site curves from which the site qualities were read were accurate for young stands up to 160 years, but beyond that age were extended, based on all the available but nevertheless insufficient data, and consequently the site qualities established for the older plots in this study, while probably correct, can not be considered as absolutely so. Furthermore, in a few of the oldest plots there were scarcely enough dominant and codominant trees without broken tops to make determination of site quality possible. The site index—that is, the average height of the dominant and codominant trees at 100 years of age—is given in column 4. This was determined in order to give an exact basis for comparison between plots on the same site. The plots fall in Sites I, II, and III, which is to be expected, in as much as, according to McArdle (*14*), about 98 per cent of all Douglas fir land in this region comes within these three classes.

The age of individual trees was determined at stump height, and this age was corrected to ground level by the addition of the number of years required for the average tree to grow to stump height, read from an age-height curve for Douglas fir seedlings. The average age of the felled trees in each plot is given in column 5. Previous investigations (*15*, *22*) had shown that young stands of Douglas fir on the whole were even aged, so that it was also assumed that this would hold in mature and overmature stands. The results of this study, which is the first work that has been done on old-growth Douglas fir, show that these stands are not so uniformly even aged as was thought and in extreme cases may even approach the character of an uneven-aged stand. It must be remembered that these plots were measured during four successive years on logging operations scattered throughout the Douglas fir region in the Cascade Mountains; that their selection depended strongly on the location of logging operations; and that therefore they should be a good sample of conditions existing in overmature stands. No adequate explanation of the tendency for stands to become somewhat uneven aged can be offered, since special study has not been made of this. In part, this condition may be explained by the fact that it is usual to find individual trees or groups

that have died, scattered through mature and overmature stands. It is reasonable to suppose that the resulting openings are frequently occupied by seedlings, some of which manage to develop under the partial shade; since these openings occur from time to time, the new trees resulting are of different ages. The cause of this dying of Douglas fir, individually or in small groups, has not been determined.

The average height given in column 7 is not based on all the trees in the plot, since those trees with broken tops were necessarily excluded from this calculation. In the younger plots, where few trees had broken tops, the basis of trees for average height is little reduced, but in the older plots, where broken tops were common, the basis is naturally much reduced. However, the figure of average height is seldom used in this study for comparative purposes.

In columns 8 and 10 are given the gross volumes in board and cubic feet of all the Douglas firs of merchantable size measured on the plot, but changed to a per-acre basis to permit direct comparison between plots; while columns 9 and 11 show the percentage relation of these volumes to the gross volume of all the trees of all species on the plot, whether standing or felled. Although every effort was made to select plots of pure Douglas fir where all trees of merchantable size were cut, this was not always possible, so that some of the plots had a small number of trees of other species of merchantable size. Furthermore, trees too small to be merchantable, particularly western hemlock, were common; and since all trees of all species 12 inches in diameter breast high or larger are included in the total volume for each plot, this still further increases the volume of trees other than felled Douglas fir of merchantable size on the plots. Most of these small trees are knocked down and destroyed in logging. There were 3,496 trees of all species 12 inches or larger in diameter breast high on the 38 plots. The heights of standing trees were measured with a Forest Service standard hypsometer. These measurements, together with the diameter breast high, made it possible to compute the board and cubic-foot volume of each tree from taper curves.

The number of trees on each plot is given in column 12 and serves as a basis for computations. This includes only Douglas firs of merchantable size, practically all of which were felled. On some logging operations trees judged to be unmerchantable because of decay are left standing, and it was impossible entirely to avoid such operations in locating plots. The volumes of such trees were obtained from taper curves based on diameter breast high and height; their ages were taken either as the average age of the felled trees on the plot or the average age of several trees of the same size and character immediately surrounding them; the percentages of cull from various causes were considered the same as that found by actual measurement of the felled trees, except decay, which was closely estimated by hypsometer measurements on the heights of conks or swollen knots, as will be explained later. Furthermore, the loss through decay was deducted before allowance was made for losses from other causes. Altogether there were 50 such standing Douglas firs of merchantable size among the 2,633 trees included in this study. They stood on 12 of the plots studied, in numbers varying from 1 to 8 on a plot, and averaging 4 to the plot.

Curves (fig. 3) showing the gross volume per acre in board and cubic feet, according to the age of the trees, were prepared for the

plots on Site II, to permit determinations of the volumes per acre at various ages. As is customary with yield data, the gross volumes without deduction for defect of any kind are used. The plots are averaged into 50-year age classes from 51 to 100 years, 101 to 150 years, and so on, a point being plotted for each age class. Owing to the few plots on Sites I and III, curves could not be drawn for them. The lower ends of these curves are shaped in accordance with similar curves [4] based on an adequate number of plots in fully stocked stands but extending only to 160 years. A comparison shows that the curves presented here for Site II are somewhat lower up to 160 years than the curves for fully stocked stands. Since the loca-

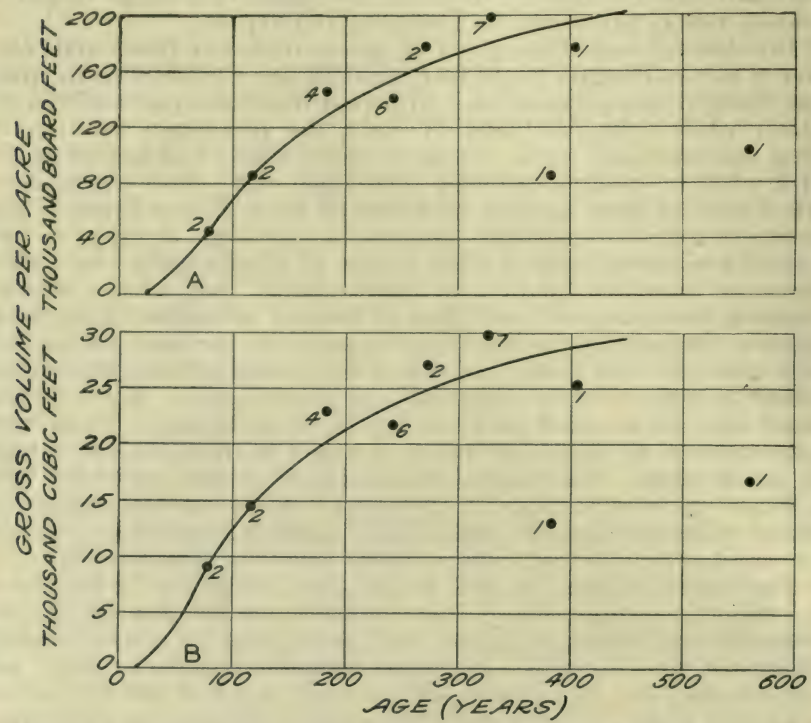

FIGURE 3.—Gross volume per acre of Douglas firs of merchantable size in relation to age on Site II: A, Board feet (Scribner Decimal C rule); B, cubic feet

tion of plots in this study was controlled by the location of logging operations, it was not possible to select all the plots in fully stocked stands, and in some cases it was apparent that the stands were decidedly understocked. This accounts for the lower yield shown by this figure. However, this lower yield accords with existing conditions, because subnormal stocking is the usual condition in the present Douglas fir stands (*19, p. 641*). Beyond 160 years of age there is no basis for comparison, and it is impossible to determine whether the values given in these curves are lower or higher than they would be for fully stocked stands. Although these curves represent the only

[4] Prepared by the Pacific Northwest Forest Experiment Station for a yield study of Douglas fir.

yield data yet available for mature and overmature stands, it must be emphasized that they are applicable only for the purpose of this study, that is, to show the relation between growth and decay, since they are based on a small number of plots and on stands part of which are not fully stocked. Theoretically these curves might decline in the older-age classes because of the well-known tendency of greatly overmature Douglas fir stands to break up and be replaced by western hemlock. However, the usual age at which this breaking up begins is not known and might be beyond the limits of these curves. There need be no further discussion of these curves, as their use will be brought out later.

CAUSES OF LOSS

Although it is well known that losses in Douglas fir timber are high, particularly in the older stands, no exact figures on these losses have shown the amount or the relative importance of the various causes of cull. Incidental to this study of decay, it was possible, with a little additional field work, to take measurements on other classes of cull. After all, it is not only the loss from decay that must be considered in stands but the total loss from all causes. In Table 2 is shown the cull percentage based on the total board and cubic foot volume of all the plots combined. Decay is by far the most important cause of loss, amounting to 16.99 per cent in board feet. It is followed by breakage in felling, amounting to 9.25 per cent; these two factors alone account for 26.24 per cent in the 27.77 per cent total loss. Shake amounted to 0.93 per cent. Certain losses were individually so unimportant that they were combined with losses from similar causes into a broad classification, called "miscellaneous defect," in order to simplify the presentation of loss figures throughout the remainder of this bulletin.

TABLE 2.—*Percentage of loss in Douglas firs of merchantable size based on gross board and cubic foot volumes*

[Basis: 38 plots, 2,633 trees, 10,146,530 board feet, 1,571,368 cubic feet]

Causes of loss	Percentage of loss [1] in—	
	Board-foot volume	Cubic-foot volume
Shake	0.93	0.55
Miscellaneous defects:		
Broken top	.02	.04
Volunteer	Trace.	Trace.
Crook	Trace.	Trace.
Fork	.06	.07
Knots	.52	.62
Insects	Trace.	Trace.
Fire scar	Trace.	Trace.
Check	Trace.	Trace.
Total	.60	.73
Breakage in felling	9.25	12.57

Causes of loss	Percentage of loss [1] in—	
	Board-foot volume	Cubic-foot volume
Rots:		
Red ring rot (Trametes pini)	13.72	7.52
Red-brown butt rot (Polyporus schweinitzii)	1.06	.75
Yellow-brown top rot (Fomes roseus)	.69	.38
Brown trunk rot (Fomes laricis)	1.46	.80
Pitted sap rot (Polystictus abietinus)	.02	.02
Spongy sap rot (Fomes annosus)	.02	.01
Brown cubical rot (Polyporus sulphureus)	0	Trace.
Unknown rots	.02	.01
Total	16.99	9.50
Total loss from all causes	27.77	23.35

[1] Trace means that percentage of loss was less than 0.01.

It will be noticed that the percentage of loss by several causes, notably breakage in felling, is higher in cubic feet than in board feet. This is because of the scaling rules in effect for board-foot measure, which state that a log 66⅔ per cent unmerchantable must be scaled as 100 per cent unmerchantable. Consequently a log with 66⅔ per cent of its gross merchantable board-foot volume lost through decay was considered in this study to be a complete loss. If such a log was also broken it was still classed as completely unmerchantable in board feet because of rot, since this last defect appeared before breakage. In cubic feet, however, the actual volume of decayed wood was charged against decay, while the remainder of the loss was considered breakage in felling. Naturally this would give, in cubic feet, a greater relative loss in breakage in felling. Cubic-foot figures on loss in this study are an exact measure of the actual volume of wood lost from the gross volume of the tree, while board-foot figures express this loss from the gross merchantable volume of the tree according to logging and milling practice, measured by empirical rules. The two sets of figures are not comparable, nor are they convertible.

While Table 2 was based on the gross volume of all the Douglas firs of merchantable size, Table 3 gives the losses by individual plots arranged by ages, beginning with the youngest plot. The average figures at the end of the table are a direct average with each plot given equal weight. In Table 4 the plots have been grouped into 50-year age classes to demonstrate the relation of age to certain defects, a relation which will be brought out later in the discussion.

TABLE 3.—*Loss in Douglas firs of merchantable size by plots, based on gross board and cubic foot volumes per acre*

Plot No.	Average age	Percentage of loss [1] in—									
		Board-foot volume					Cubic-foot volume				
		Rot	Shake	Miscellaneous defect	Breakage in felling	Total	Rot	Shake	Miscellaneous defect	Breakage in felling	Total
1	2	3	4	5	6	7	8	9	10	11	12
	Years										
11	64	Trace.	0	0.2	2.7	2.9	Trace.	0	0.1	2.9	3.0
4	66	0	0	.1	1.0	1.1	0	0	.1	1.3	1.4
32	94	.9	.7	.1	2.6	4.3	.6	.2	.1	2.7	3.6
1	103	3.2	0	.1	9.5	12.8	1.3	0	.3	12.3	13.9
6	112	.2	.6	.1	6.9	7.8	.2	.4	.1	8.9	9.6
2	114	8.7	Trace.	.6	4.5	13.8	3.8	Trace.	.8	6.4	11.0
5	116	2.3	1.1	1.8	2.7	7.9	1.6	.3	2.1	3.9	7.9
33	122	2.9	.6	.1	6.3	9.9	1.3	.4	.1	8.3	10.1
29	145	6.2	2.0	.1	1.8	10.1	3.4	1.5	.1	2.8	7.8
3	149	5.4	.2	0	6.8	12.4	3.3	.1	0	9.4	12.8
8	158	4.3	1.0	.2	7.2	12.7	2.1	.6	.2	9.2	12.1
26	183	14.5	.8	4.8	10.1	30.2	7.3	.5	6.0	13.0	26.8
14	197	4.1	.3	0	6.9	11.3	2.4	.3	0	10.0	12.7
7	198	6.8	1.6	2.5	6.6	17.5	3.6	1.3	2.9	8.7	16.5
15	204	.2	.1	.2	7.5	8.0	.1	Trace.	.1	9.5	9.7
10	232	7.0	.3	Trace.	9.5	16.8	3.7	.2	Trace.	12.0	15.9
12	237	17.9	.3	0	8.2	26.4	10.6	.3	0	11.5	22.4
16	238	1.6	.1	.1	6.4	8.2	1.0	.1	.1	8.4	9.6
27	243	8.0	.8	0	7.6	16.4	4.7	.5	0	10.4	15.6
35	245	3.5	1.2	0	7.4	12.1	1.9	.7	0	9.6	12.2
25	245	29.8	.3	6.3	13.0	49.4	16.9	.2	7.5	16.9	41.5
17	245	.2	.2	0	9.7	10.1	.1	.1	0	11.8	12.0

[1] Trace means that percentage of loss was less than 0.01.

TABLE 3.—*Loss in Douglas firs of merchantable size by plots, etc.*—Continued

Plot No.	Average age	Percentage of loss in—									
		Board-foot volume					Cubic-foot volume				
		Rot	Shake	Miscellaneous defect	Breakage in felling	Total	Rot	Shake	Miscellaneous defect	Breakage in felling	Total
1	2	3	4	5	6	7	8	9	10	11	12
	Years										
36	258	22.5	2.0	0	5.3	29.8	11.6	0.8	0	8.8	21.2
30	289	3.5	1.4	Trace.	6.4	11.3	2.3	.4	Trace.	8.5	11.2
24	309	16.0	.3	0	12.2	28.5	8.5	.1	0	17.7	26.3
22	316	24.0	1.2	Trace.	11.3	36.5	13.9	.4	Trace.	17.1	31.4
38	319	54.8	1.3	Trace.	5.4	61.5	32.2	.6	.1	9.1	42.0
37	322	45.5	1.3	0	9.4	56.2	26.8	.5	0	15.1	42.4
18	333	12.2	2.3	.2	8.3	23.0	7.7	2.8	.2	10.2	20.9
31	333	22.3	2.9	Trace.	7.7	32.9	13.6	1.1	Trace.	11.2	25.9
21	340	29.4	.9	0	14.0	44.3	17.2	.5	0	20.2	37.9
13	345	13.7	1.1	.4	13.8	29.0	8.0	.8	.4	17.7	26.9
20	349	12.5	.5	Trace.	16.0	29.0	7.0	.2	Trace.	19.9	27.1
34	383	12.0	2.0	.1	13.4	27.5	7.7	1.1	Trace.	16.5	25.3
9	400	5.2	1.2	.1	7.9	14.4	3.4	.6	.1	10.4	14.5
23	404	30.9	.3	Trace.	13.3	44.5	17.5	.2	Trace.	20.6	38.3
28	412	30.0	1.2	0	7.3	38.5	16.9	.4	0	12.8	30.1
19	559	8.2	.4	.1	9.4	18.1	5.1	.3	.3	11.4	17.1
Average	247	12.4	.9	.5	8.0	21.8	7.1	.5	.6	11.0	19.1

TABLE 4.—*Loss in Douglas firs of merchantable size by plots grouped in 50-year age classes, based on gross board and cubic foot volumes per acre*

Age class	Average age	Percentage of loss[1] in—										Plots (basis)
		Board-foot volume					Cubic-foot volume					
		Rot	Shake	Miscellaneous defect	Breakage in felling	Total	Rot	Shake	Miscellaneous defect	Breakage in felling	Total	
1	2	3	4	5	6	7	8	9	10	11	12	13
	Years											*Number*
51 to 100	75	0.3	0.2	0.1	2.1	2.7	0.2	0.1	0.1	2.3	2.7	3
101 to 150	123	4.1	.6	.4	5.5	10.6	2.1	.4	.5	7.4	10.4	7
151 to 200	184	7.4	.9	1.9	7.7	17.9	3.9	.7	2.3	10.2	17.1	4
201 to 250	236	8.5	.4	.8	8.7	18.4	4.9	.3	1.0	11.3	17.5	8
251 to 300	274	13.0	1.7	Trace.	5.9	20.6	7.0	.6	Trace.	8.7	16.3	2
301 to 350	330	25.6	1.3	.1	10.9	37.9	15.0	.8	.1	15.4	31.3	9
351 to 400	392	8.6	1.6	.1	10.7	21.0	5.6	.9	.1	13.5	20.1	2
401 to 450	408	30.5	.8	Trace.	10.3	41.6	17.2	.3	Trace.	16.7	34.2	2
551 to 600	559	8.2	.4	.1	9.4	18.1	5.1	.3	.3	11.4	17.1	1

[1] Trace means that percentage of loss was less than 0.01.

SHAKE

The common shake was ring shake following the annual rings. Star shake or radial shake from the center of the tree toward the outside or from the outside part way to the center, the latter so characteristic of frost cracks, was seldom found. Shake was not confined to the butts of trees but was most frequent there. While shake might be found anywhere in the trees, it was nearly always in

the lower half of the trunk and consequently caused more serious losses than the figures indicate, since it is from the lower bole that most of the high-grade logs come. As has been brought out before (*27*), shake is particularly apt to develop at a point of weakness in the wood. It was not uncommon to find shake connected with a lightning ring, that is, an annual ring with a layer of cells changed in both structure and shape from the normal by an electrical discharge which affected the cambium. A lightning ring forms a plane of cleavage in wood.

To determine the loss from shake in board-foot volume, the standard scaling practice of the Forest Service (*30*, *p. 20*, *22*) was followed. In cubic-foot volume in the case of ring shake, the width of the shake was measured at each end of the log and the volume of the shake computed as a hollow cylinder. If the shake appeared on only one end of the log, its lineal extent was estimated.

From Table 2 it can be seen that the complete loss from shake amounted to 0.93 per cent of the gross board-foot volume, a relatively small percentage. In Table 4 shake shows a tendency to increase in amount with the increase in the age of the stand, but this increase is not striking. Shake may appear rather early in the life of the stand, for in plot 32, age 94 years, there is 0.7 per cent loss from this cause (Table 3); and in plot 5, age 116 years, there is 1.1 per cent loss; while the maximum loss is 2.9 per cent in plot 31, age 333 years. Curves showing the percentages of loss in board and cubic feet resulting from shake have been prepared (fig. 4) to bring out more clearly the increase in shake with increasing age of the stand.

MISCELLANEOUS DEFECTS

Under the classification of miscellaneous defects are grouped a number of defects which individually are of little consequence, but which in the aggregate cause a measurable loss—in this study 0.60 per cent of the total volume in board feet, as shown in Table 2. Of this loss 0.52 per cent is chargeable to knots, in the case of logs with so many limbs that no merchantable lumber could be sawed from them. Such logs are commonly found in the upper bole near the merchantable diameter limit or in "wolf" trees; that is, trees which have grown much faster than their neighbors and consequently have not self-pruned properly. The loss from broken tops amounted to 0.02 per cent. Breaking off of tops by wind or other agencies is common in Douglas fir, particularly in overmature stands, or in a young stand that has suffered from an ice storm. Frequently checking or staining occurs for a few feet down the trunk, even if decay does not enter subsequently. This results in a little cull when the trees are felled. The only other loss of sufficient volume to make a definite figure was "fork"; that is, the volume lost in bucking out the actual fork in forked trees. This amounted to 0.06 per cent.

The loss in volunteers was very small. This was found in broken-topped trees where a limb had replaced the missing top, becoming a volunteer top. At the point where the top joined the main bole there was always a crooked portion unfit for lumber. Douglas fir is naturally a tall, straight tree; hence the cull from crook was negligible. Wood-boring insects and checks were likewise unimportant. There were very few fire scars found in the trees. This is because

ground fires are not common in the Douglas fir region. When fire does occur it is usually sufficiently intense to kill the trees outright.

An examination of Table 4 indicates that there is very little relation between miscellaneous defects and age. This is to be expected since some of the factors making up this classification are little affected by age after the trees have passed the small-pole stage. Among these are crook, fork, knots, and fire scars. In fact, short

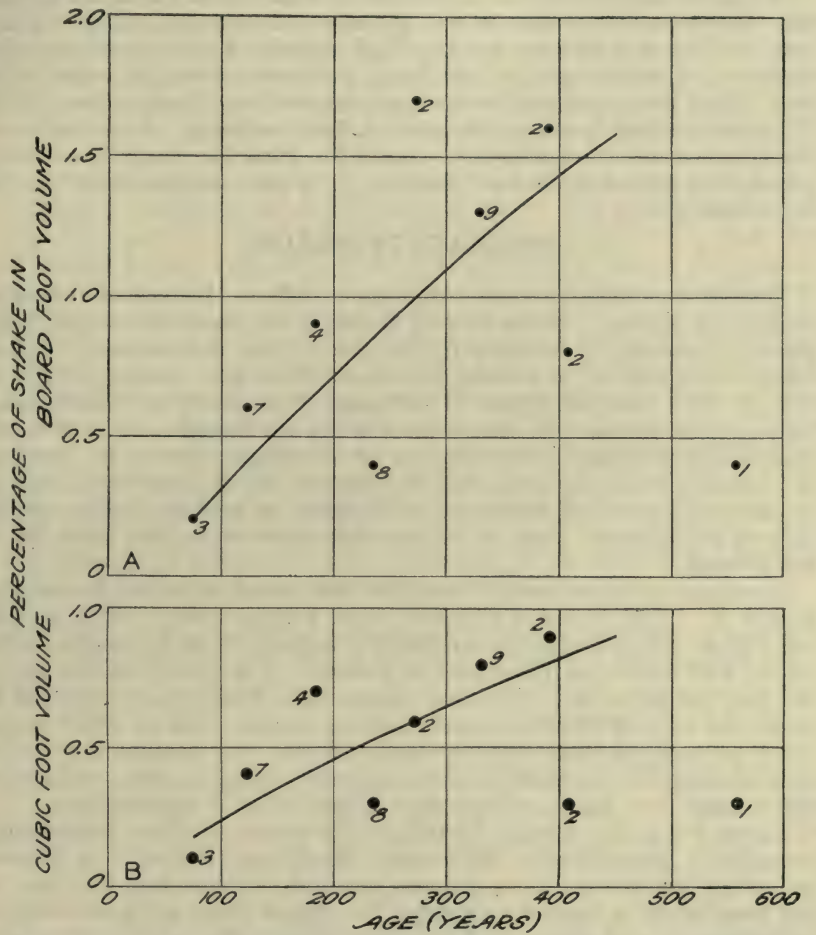

FIGURE 4.—Percentage of shake in relation to age of Douglas firs of merchantable size based on gross volume per acre: A, Board feet (Scribner Decimal C rule); B, cubic feet

crooks which are common in the upper boles of young trees that have suffered broken tops from snow and ice storms tend to straighten out as the trees become older and diameter increases. The greatest loss from miscellaneous defects, 1.9 per cent, occurs in the 151 to 200 year age class and is attributable to two plots, as is shown in Table 3—No. 26 with 4.8 per cent loss, and No. 7 with 2.5 per cent loss—for which the original data show that knots were responsible. In fact, in every plot where miscellaneous defects were more than 0.5

per cent, knots were the principal cause. It may be that the losses from knots in the understocked stands represented by many of these plots, are higher than would be found in fully stocked stands, since there should be a greater development of branches in the more open understocked stands.

WASTE

On most logging operations there is some waste; that is, timber lost that could have been saved by more careful utilization. Common sources of waste are leaving high stumps, leaving merchantable timber in breaks, tops or cull logs, and overlooking merchantable logs. This loss is affected by general market conditions, accessibility of the individual operation to market, and the policy of the operator. Some operators are naturally wasteful. Because waste is so completely controlled by human factors, it is not considered further in this bulletin.

BREAKAGE IN FELLING

Next to decay the most serious cause of loss in this region is timber broken in felling. Hanzlik and Fuller (*10*) have presented some data on breakage in Douglas fir, but aside from this there is no published information available on losses from this cause. Wagener (*31, p. 640*) lists the types of breakage that occur in Pacific-coast logging operations. In the present study on Douglas fir it was not possible to determine the amount of breakage caused by yarding and loading—that is, dragging the logs to the railroad and loading on cars—therefore all reference to breakage or broken timber applies only to the damage done in felling and apparent as the trees lie on the ground.

Breakage is an extremely variable loss, since so many factors influence it. The personal element plays a large part. Skillful timber fellers can get trees down with a minimum of breakage, while others will destroy a great deal of timber. The policy of the operator has its influence. In some camps the fellers are expected to break the tops of trees to avoid bucking expense, but in other camps effort is made to save even top logs. Again, the market may influence breakage since there is more tendency toward closer utilization when there is a good market than when there is a poor one.

Aside from the human factors, it is apparent that topography necessarily is extremely important. Breakage naturally is greater on rough ground than on smooth ground. Then, too, the size of the trees must be considered, since the larger trees are more subject to breakage; and since, within broad limits, size is related to age, older stands show more breakage than younger, other factors being equal. Finally, the stand per acre is important—the denser the stand, the greater the difficulties in felling and the higher the rate of breakage. In considering the loss from breakage, it must be remembered that the actual loss is not quite so serious as the figures indicate. Most breakage occurs in the upper part of the boles, where the majority of the knotty, low-grade logs are found.

The cubic-foot volumes of broken sections, irrespective of length, were computed directly by the Smalian formula. The board-foot

volumes were scaled directly for the sections 6 feet in length or longer. Sections less than 6 feet long were scaled pro rata on the basis of their length. For example, a 6-foot section 12 inches in diameter inside the bark at the small end contains 30 board feet. A section with the same diameter, but 4 feet long, would contain 20 board feet; one 3 feet long, 15 board feet. In small pieces the board-foot measure was carried to the nearest 5 feet, and not rounded off to the nearest 10 in accordance with the Scribner Decimal C rule until final computations were made on groups of trees or plots. Broken sections less than 6 feet long were not common.

Table 2 shows a loss from breakage in gross board-foot volume of all the Douglas firs of merchantable size amounting to 9.25 per cent. Table 3, in which the various losses are given for individual plots, shows (column 6) that breakage is variable, the lowest figure in board-foot volume being 1 per cent in a 66-year-old plot and the highest 16 per cent in a 349-year-old plot. But young timber does not necessarily have low breakage, since a 103-year-old plot shows a loss of 9.5 per cent and a 412-year-old plot a loss of 7.3 per cent. However, there is a definite tendency for breakage to increase with age up to a certain limit, as is brought out in Table 4, column 6, which tendency is partly interfered with by the other variables.

To determine the influence of topography and density of the stand on breakage, the plots were divided into two classes, those on rough ground and those on smooth ground. Rough ground included areas with steep slopes, cut up by numerous small ravines, or with rock outcrops. These features might be alone or in any combination. Smooth ground included only level areas and those with gentle to moderate slopes, without ravines or rock outcrops. These two groups of plots were then compared as to their gross stand per acre in board feet. The data are presented in Table 5.

TABLE 5.—*Breakage in felling Douglas firs of merchantable size on smooth and rough ground by plots, grouped by gross volume per acre in board feet*

Gross volume per acre class (M bd. ft.)	Smooth ground						
	Average diameter breast high	Average height	Average gross volume per acre in—		Breakage in felling in—		Plots (basis)
			Board feet	Cubic feet	Board-foot volume	Cubic-foot volume	
1	2	3	4	5	6	7	8
	Inches	*Feet*			*Per cent*	*Per cent*	*Number*
1 to 50	23.2	142	43,830	8,397	3.5	4.6	2
51 to 100	30	162	78,110	12,045	5.3	7.1	5
101 to 150	57.6	205	125,950	19,160	7.7	10.5	6
151 to 200	45.6	212	169,030	25,910	8.7	12.1	9
201 to 250	47.9	218	231,390	35,186	10.1	13.8	4
251 to 300	74	255	294,870	43,684	7.3	12.8	1
Average or total	45.1	198	147,250	22,581	7.6	10.5	27

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TABLE 5.—*Breakage in felling Douglas firs of merchantable size, etc.*—Continued

Gross volume per acre class (M bd. ft.)	Rough ground						
	Average diameter breast high	Average height	Average gross volume per acre in—		Breakage in felling in—		Plots (basis)
			Board feet	Cubic feet	Board-foot volume	Cubic-foot volume	
1	9	10	11	12	13	14	15
	Inches	*Feet*			*Per cent*	*Per cent*	*Number*
1 to 50	24.6	132	32,290	5,879	5.5	7.5	4
51 to 100	47.9	193	83,600	13,178	9.9	12.4	2
101 to 150	43.4	200	124,580	19,530	10.4	14	3
201 to 250	50	247	222,760	32,801	14	20.2	1
251 to 300	51.5	223	253,400	38,161	16	19.9	1
Average or total	38.7	180	104,200	16,311	9.3	12.4	11

This table shows a definite tendency for the percentage of breakage to increase with the increased density of the stand in both board and cubic foot volume. It is also apparent that breakage on rough

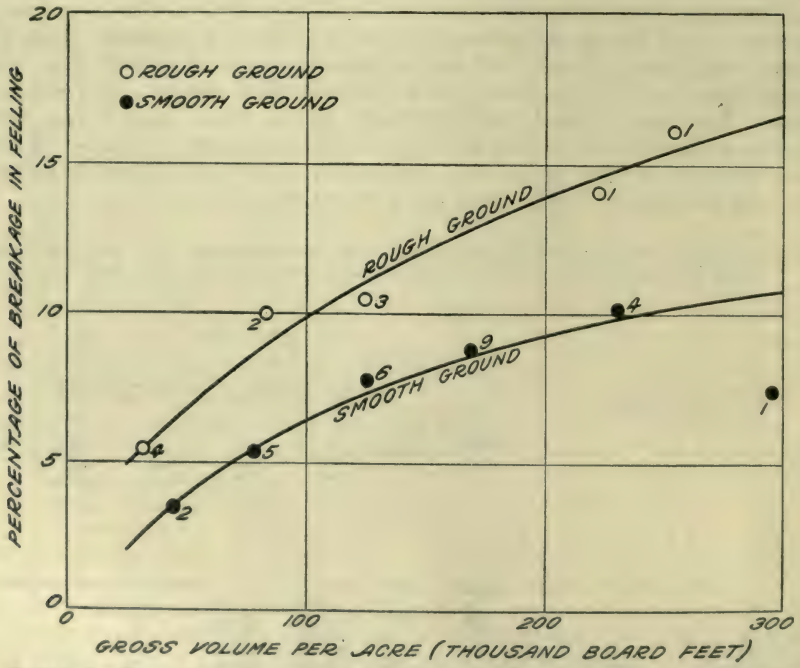


FIGURE 5.—Percentage of breakage in felling in Douglas firs of merchantable size on rough and smooth ground by plots in relation to gross volume per acre in board feet. (Scribner Decimal C rule)

ground amounting to 9.3 per cent in board-foot volume (Table 5, column 13) was greater than that on smooth ground, which amounted to 7.6 per cent. (Table 5, column 6.) This apparent difference is even more marked when it is considered that the stand per acre on rough

ground is less than that on smooth ground, 104,200 board feet on the former (column 11) as compared with 147,250 board feet on the latter (column 4), and the trees also are smaller in average diameter breast high and in average height; while it is in the less dense stands with smaller trees that the least breakage should be expected, other conditions being equal.

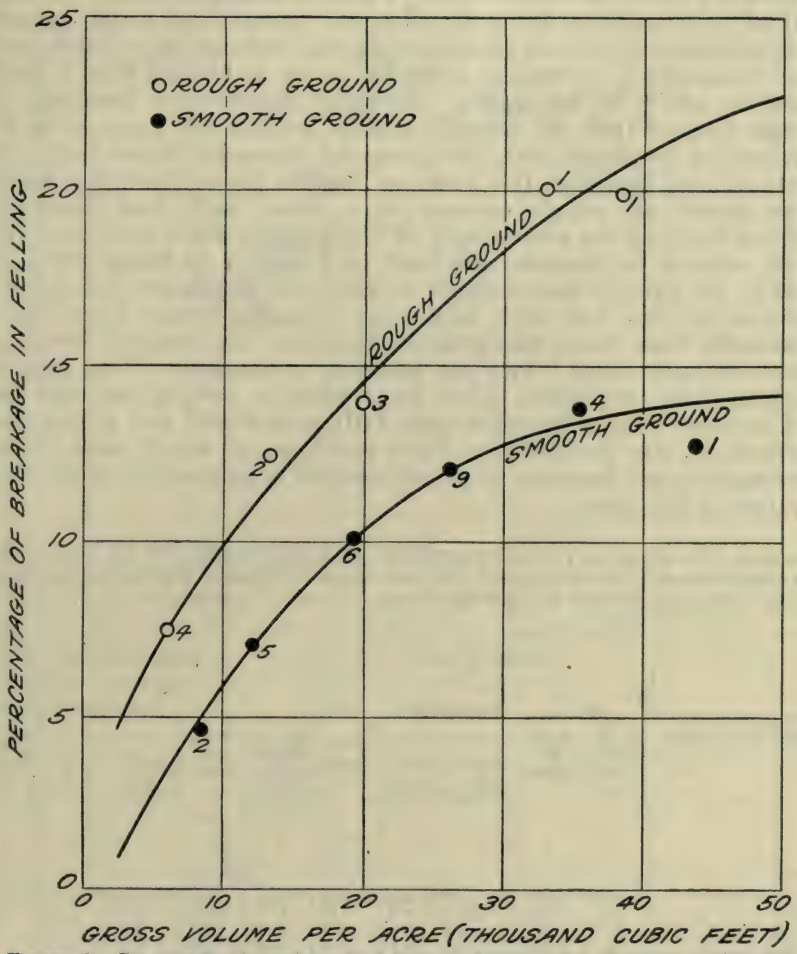


FIGURE 6.—Percentage of breakage in felling in Douglas firs of merchantable size on rough and smooth ground by plots in relation to gross volume per acre in cubic feet

In order to bring out more clearly the increase in breakage with the increased density of the stand and the difference between rough and smooth ground, the data in Table 5 for board and cubic feet are shown in Figures 5 and 6. The curves show a marked difference between the two types of ground, together with increased breakage with increased density of the stand.

The previous consideration of breakage has been on the basis of plots and included trees with a large amount of decay which exerts some influence on breakage. The presence of decay may influence

the actual breaking of the tree when it is felled. Then, too, in measuring in board feet, decay often conceals an actual loss in breakage. For example, under the scaling rules a log that is two-thirds or more unmerchantable, owing to decay, is classed as completely unmerchantable, and the loss is charged against rot, even though there might have been some loss caused by breakage in the remaining third of the volume. Table 6, which is based on individual trees selected from the plots on smooth and rough ground and arranged by 8-inch diameter classes, includes only those trees free from decay, or with so little rot or rot so located that it could have no effect on breakage. The table shows more breakage on rough ground than on smooth, and in general an increase in the amount of breakage with the increased diameter breast high. In spite of the fact that the trees on smooth ground average larger than those on rough ground they show still less breakage. Curves showing the percentages of breakage in board and cubic feet with relation to diameter are used in Figure 7 to bring out more clearly the greater loss through breakage on rough ground and the increase in this loss with increasing diameter breast high. It is noticeable that when the greater diameters are reached breakage increases more slowly with the increase in diameter. This may be explained by two facts: After trees attain a certain size they are not so easily broken by other trees falling on them; and as the trees increase in size the volume of the top logs, in which most of the breakage occurs, becomes relatively smaller in proportion to the total volume of the tree.

TABLE 6.—*Breakage in felling Douglas firs of merchantable size on smooth and rough ground by trees grouped in 8-inch diameter classes, based on gross board and cubic-foot volume per average tree*

Diameter breast-high class (inches)	Smooth ground					Rough ground				
	Average diameter breast high	Average height	Breakage in—		Trees (basis)	Average diameter breast high	Average height	Breakage in—		Trees (basis)
			Board-foot volume	Cubic-foot volume				Board-foot volume	Cubic-foot volume	
1	2	3	4	5	6	7	8	9	10	11
	Inches	*Feet*	*Per cent*	*Per cent*	*Number*	*Inches*	*Feet*	*Per cent*	*Per cent*	*Number*
16	16.4	130	2.3	3.2	179	17.8	117	6.8	7.1	65
24	24.3	155	5.3	7.1	254	23.8	137	5.6	7.4	140
32	32.2	184	7.5	10.2	356	31.8	164	7.3	9.9	118
40	39.8	204	8.1	11.0	324	40.2	192	10.5	13.1	90
48	48.0	216	8.9	12.5	222	48.0	213	14.3	16.5	66
56	55.8	224	10.2	13.0	137	55.4	226	17.0	18.7	48
64	63.4	232	13.0	15.6	46	63.7	241	13.2	17.3	22
72	72.7	240	13.9	16.8	29	72.0	244	14.6	17.0	13
80	79.8	240	12.5	12.9	23	76.7	239	17.4	19.2	3
88	87.2	213	12.5	13.1	8	90.0	268	42.1	44.3	1
96	95.5	240	12.6	13.7	4	95.2	252	18.9	21.9	1
104	103.5	234	9.7	11.2	4	------	------	------	------	------
120	120.0	225	4.2	6.0	1	------	------	------	------	------
Average or total	38.0	189	7.5	10.0	1,587	36.0	173	9.5	11.6	567

Although for this study plots of as nearly pure Douglas fir as possible were selected, some of the stands had a light admixture of other species. While in all such plots the Douglas fir greatly outnum-

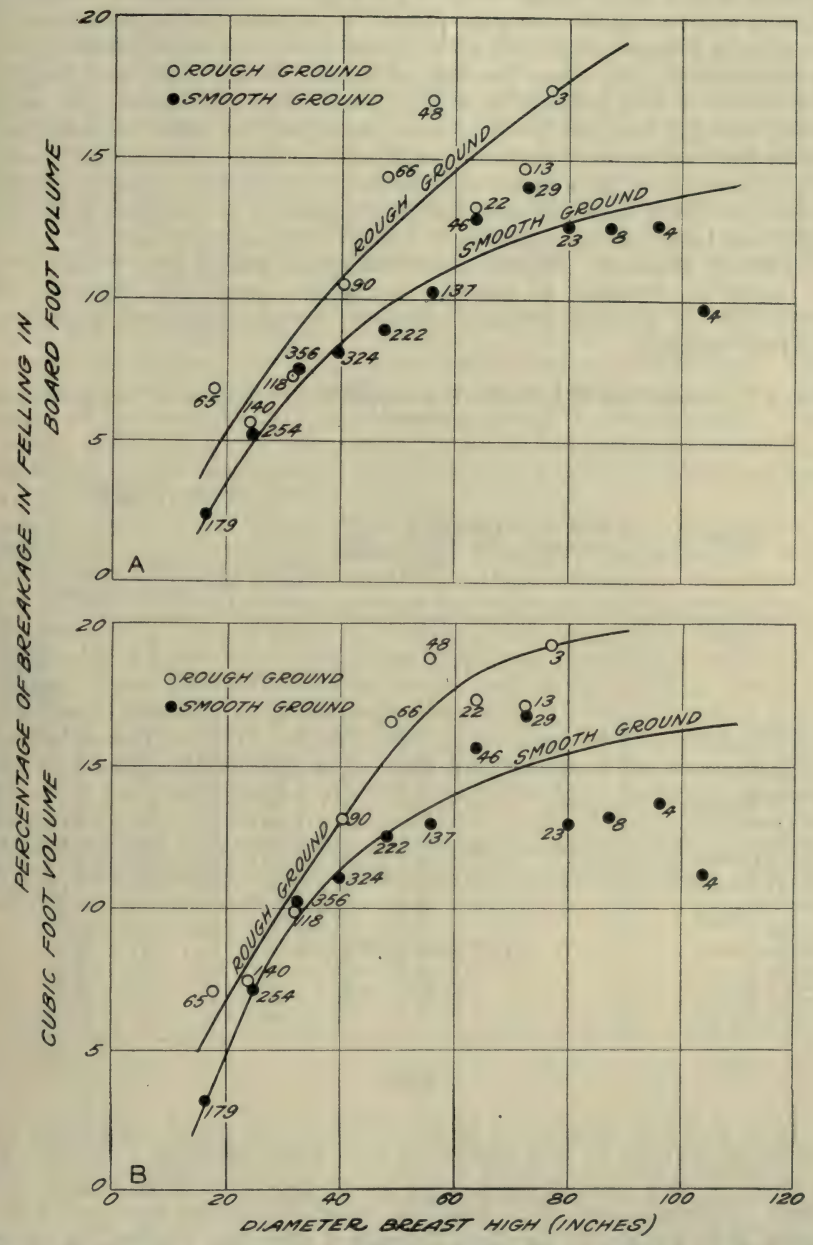


FIGURE 7.—Percentage of breakage in felling of Douglas fir on rough and smooth ground in relation to diameter breast high based on gross volume per average tree: A, Board feet (Scribner Decimal C rule); B, cubic feet

bered the other species, these other species occur in most stands. Therefore it seemed that a comparison of breakage in the different species might be of some value. In Table 7 comparative breakage figures are presented for nine plots. For these breakage figures to be exactly comparable, trees of each species on each plot should have approximately the same average diameter breast high and height. Of course it was impossible to find such ideal conditions, nor were there enough trees of other species measured to make an adequate basis for curves relating percentage of breakage to diameter breast high, thus allowing a direct comparison to be made between species. From this table it can be seen that Douglas fir is less subject to breakage than those species associated with it, the most common of which is western hemlock. Where the breakage in board feet (column 8) is higher in Douglas fir than in the other species, the Douglas fir trees have a greater average diameter breast high and a greater average height.

TABLE 7.—*Comparison of breakage in felling between Douglas fir and associated species*

Species	Type of ground	Plot No.	Average diameter breast high	Average height	Average gross volume per tree in—		Breakage in felling in—		Trees (basis)
					Board feet	Cubic feet	Board-foot volume	Cubic-foot volume	
1	2	3	4	5	6	7	8	9	10
			Inches	*Feet*			*Per cent*	*Per cent*	*Number*
Douglas fir	Rough	3	31.0	142	1,500	262	6.7	10.2	85
Incense cedar	Rough	3	37.4	128	1,340	257	13.1	16.1	8
Douglas fir	do	5	25.9	134	840	161	2.8	4.0	111
Incense cedar	do	5	43.5	138	1,650	348	6.6	7.9	5
Douglas fir	Smooth	10	42.9	217	4,400	670	9.5	12.0	125
Western hemlock	Smooth	10	26.0	165	1,830	292	17.2	19.6	31
Sitka spruce	Smooth	10	25.9	175	1,940	322	7.5	9.8	11
Douglas fir	do	12	39.6	209	3,840	587	8.4	11.8	107
Western hemlock	do	12	24.5	149	1,220	211	10.0	12.2	19
Douglas fir	do	15	34.8	207	2,760	440	7.5	9.5	164
Western hemlock	do	15	27.3	157	1,620	274	5.6	7.8	13
Douglas fir	do	19	83.4	212	17,130	2,544	9.4	11.4	13
Western hemlock	do	19	33.7	151	2,300	379	4.0	6.3	7
Douglas fir	do	28	74.0	255	13,100	1,940	7.3	12.8	52
Western hemlock	do	28	36.7	175	2,550	445	10.4	16.6	6
Douglas fir	do	30	44.8	206	4,290	658	6.4	8.5	62
Western hemlock	do	30	21.4	141	920	163	9.0	11.1	8
Douglas fir	do	31	47.1	222	4,920	761	7.7	11.2	79
Western hemlock	do	31	27.0	152	1,600	277	10.0	11.7	11

ROT

In a previous paper (*4*) it was pointed out that practically all decay in Douglas fir was caused by four wood-destroying fungi. As a result of this more extensive study, several other fungi, not previously discussed, have been found to cause occasional loss, and additional information on the four important ones has become available, so that descriptions of all are necessary to an understanding of the detailed discussion of decay which follows.

In the description of rots several terms that need explanation will be used. There are various stages in decay as the wood is changed from

being sound to a condition of complete decay. In the earliest stages the wood appears to be hard and firm, the only evidence of infection being a slight color change from the normal that is easily confused with harmless color variations or discolorations. This is known as incipient decay, early decay, or advance rot. In some cases there is not even a variation in color to indicate the presence of decay, which is then known as hidden decay. After the incipient stage is passed, the wood becomes more and more noticeably affected until it is finally changed completely in appearance and structure and can be crumbled between the fingers or easily broken. This stage is known as advanced decay, typical decay, final decay, or late decay. A stage intermediate between incipient decay and advanced decay can sometimes be recognized.

In a decaying trunk all stages of rot are present, ranging up or down the tree from the advanced decay, where the fungus has been at work the longest, through the incipient decay to sound wood. The same progression may be seen on a cross section passing from the center of the decayed portion of the heartwood to the sapwood. Vertically, incipient decay may extend from a few inches to many feet beyond the area of advanced decay, varying with the individual tree and the kind of rot.

After rot has been present for a time, the fruiting bodies—sporophores, or conks—develop. These are usually quite large and may appear on the trunk, or occasionally on the branches, in the form of flat or hoof-shaped brackets, or they may appear on the ground near by, coming up from a decayed root and somewhat resembling large, dark-colored toadstools except that they have short thick stalks, and porous undersides. Their appearance invariably indicates decay in the tree. The microscopically small spores, released from the pores on the underside of the conks, are carried away by the wind. Finding a suitable place, they germinate and decay of the wood begins. The tiny fungous thread developing from the spore can not penetrate bark or living sapwood; consequently, for decay to result, a spore must alight on exposed deadwood directly connected with the heartwood. Dead branch stubs, broken tops, and open wounds offer an abundance of infection points.

DESCRIPTION OF ROTS

RED RING ROT

Red ring rot, which is commonly known as conk rot in the Douglas fir region and elsewhere as red ring rot, ring scale rot, honeycomb rot, or pecky wood rot, is caused by the ring-scale fungus, *Trametes pini* (Thore) Fr. The incipient decay is very striking, as shown in Figure 8. It appears as a pronounced reddish purple or olive-purple color against the red or yellow heartwood, and occasionally the color may be so deep as to appear brownish. Gradually the color fades as the distance from the advanced decay increases, until it is lost entirely. The color is often most pronounced in the outermost heartwood just where it joins the sapwood. The discolorations described are sometimes bounded by a narrow zone of pronounced red. As wood is little if at all weakened by the incipient rot, it is used in the lower grades of lumber. The discoloration may extend

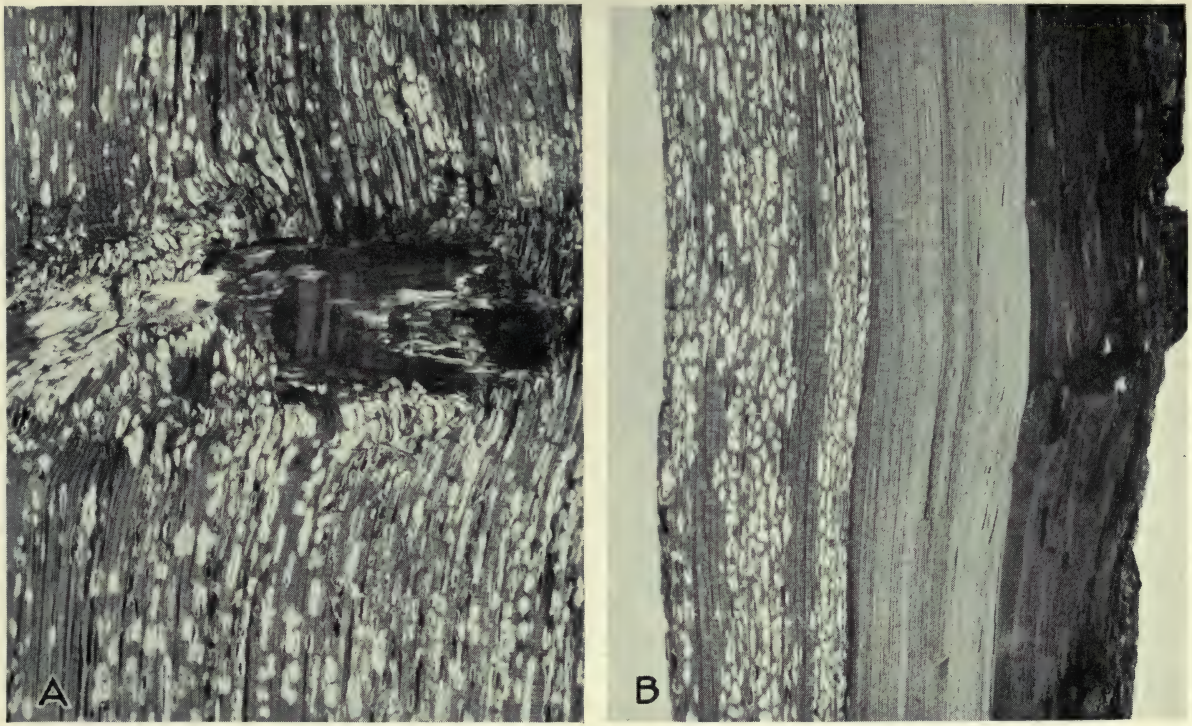
vertically 10 to 20 feet, rarely more, in advance of the cellulose pits, although 3.5 feet was found to be average. Radially the discoloration is limited to 2 or 3 inches. The red heartwood of "red" fir, which is only the normal-colored heartwood of young trees, is frequently mistaken by graders and scalers for the incipient stage of red ring rot, with the result that sound wood is culled or degraded.

In the advanced stage of rot the wood has a color the same or deeper than in the incipient stage, but is more or less riddled with spindle-shaped, slightly pointed white cavities or pockets running

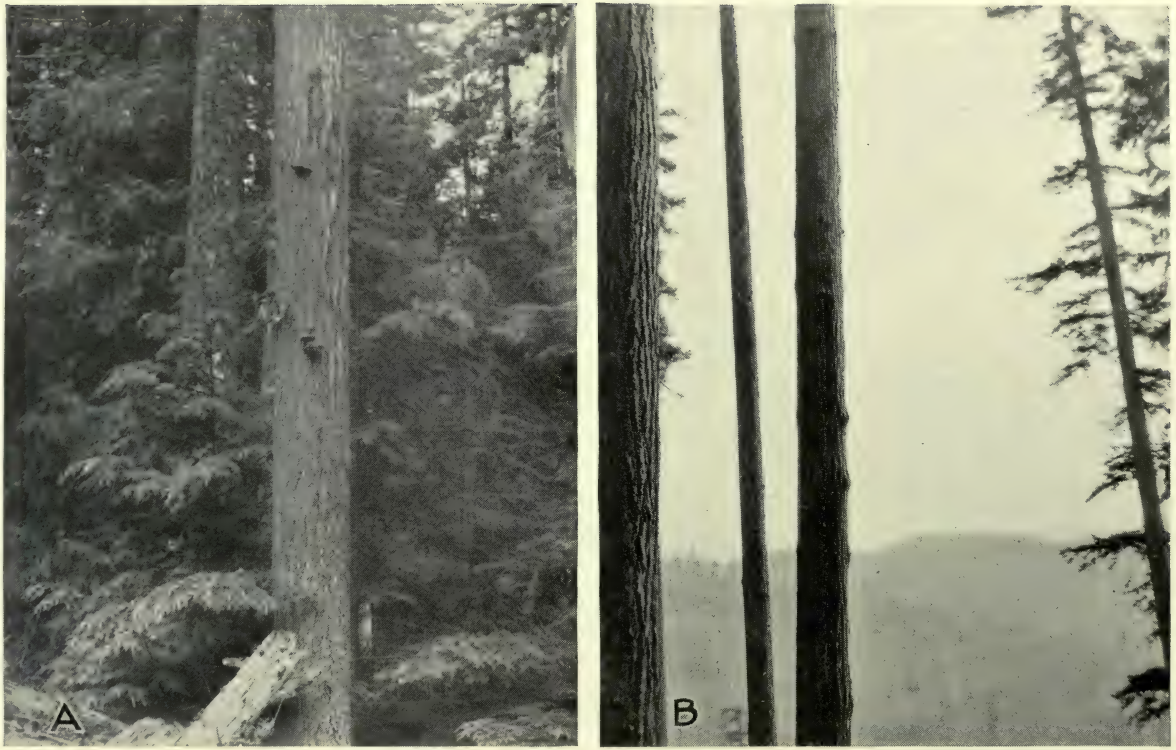
FIGURE 8.—End of a log with red ring rot caused by the ring-scale fungus, *Trametes pini*. The upper dark-colored portion of the log indicates the reddish purple stain characteristic of the incipient stage, and the lower portion shows the white cellulose pockets and the ring-scale character. (Photographed by A. H. Hodgson)

parallel to the grain and separated by firm wood, which are illustrated in Plate 1. In these pockets the wood has been reduced to a white, soft, fibrous mass of cellulose.

A number of pockets may merge, forming an irregularly shaped area of rotted wood. In some cases the pocket may contain no cellulose fibers. When seen on the cross section at the end of a log, they may be scattered rather uniformly throughout the affected wood or may be in the form of ring scale, which quite commonly results from the rot being confined to more or less definite groups of annual rings, as shown in Figure 8.



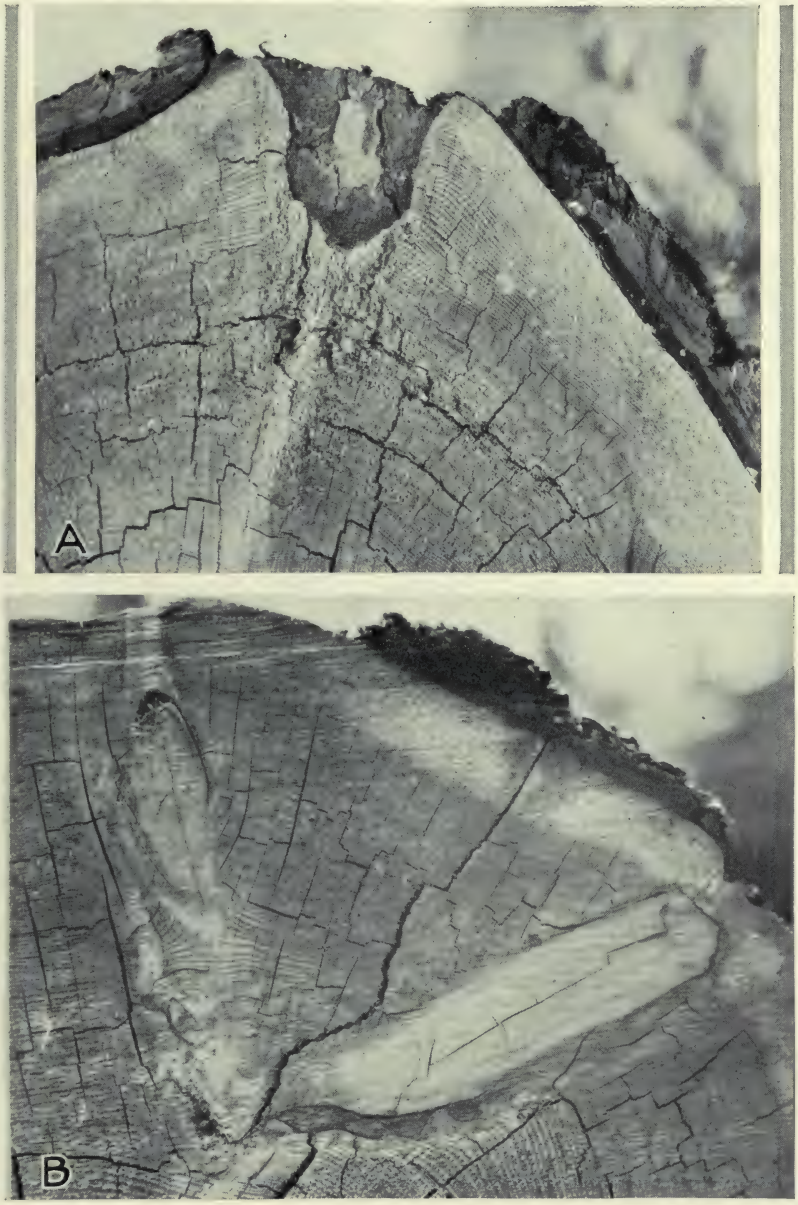
A, Radial view of the advanced stage of red ring rot caused by the ring-scale fungus, *Trametes pini*, showing a partially decayed knot; B, radial view of a decayed trunk showing the advanced stage of red ring rot (on the left), sound heartwood, sapwood, and bark



A, Conks of the ring-scale fungus, *Trametes pini*, on a Douglas fir. These conks indicate red ring rot in the heartwood. (Photograph by the writer and R. E. McArdle); B, swollen knots on a living tree indicating red ring rot caused by the ring-scale fungus in the heartwood

A, Conk, or sporophore, of the ring-scale fungus, *Trametes pini*, showing the rough upper surface and the irregular pores on the under surface. This fungus causes red ring rot; B, side view of swollen knots on a log from which the bark has been removed. (Photographs by the writer and R. E. McArdle)

A, Cross section through a Douglas fir log with red ring rot caused by the ring-scale fungus, *Trametes pini*, showing a swollen knot; B, cross section through a sound Douglas fir log showing normal knots. (Photographs by the writer and R. E. McArdle)



A, Cross section through a swollen knot. This is a detailed view of the swollen knot shown in Plate 4, A; B, cross section through sound knots. This is a detailed view of the sound knots shown in Plate 4, B. (Photographs by the writer and R. E. McArdle)

The heartwood in the butt of this Douglas fir has been completely destroyed by red-brown butt rot caused by the velvet top fungus, *Polyporus schweinitzii*. (Photograph by G. G. Hedgcock)

While red ring rot is not limited to any definite portion of the trunk, it is not frequent in the butt of the tree, seeming to find conditions there less favorable for its development. In completely decayed trees, although the rot may include nearly the entire heartwood at the top of the first 16 or 32 foot log, it is quite usual for the rotted area on the stump to be small or completely absent. The stumps usually vary from 2 to 4 feet in height.

Sawyers often observe (*1*) that many butt logs of Douglas fir are very tough and hard to saw. This may indicate that there is a greater relative amount of compression wood, with its thick cell walls, in the butt of the tree than in the upper portions. It would be more difficult for a wood-destroying fungus to decay such wood than wood of normal density. Again, the resin content or the moisture content may be higher in the butt, and either condition might have a retarding effect on rot.

Sporophores, or conks, are very common in overmature stands. (Pl. 2, A.) These perennial fruiting bodies issue from the tree through knots. They vary in size and may be bracketlike or hooflike in shape. The upper side is a dull grayish or brownish black, rough, and with approximately concentric furrows parallel to the lighter brown margin. The underside is a grayish brown or rich brown color with large irregular pores. (Pl. 3, A.) When the conk is actively growing, the margin is velvety and light golden brown in color. Its substance is corky or punky.

Besides the conks, swollen knots are developed as shown in Plate 2, B. These are merely the initial stages of sporophores, in which the substance forming the conks is growing out through the knots, and consequently is just as good an indication of the presence of decay as are sporophores. Often the sporophore never develops beyond this stage. Chopping into one of these swollen knots reveals a brown punky substance, the same as in a fully developed sporophore. In some cases the sapwood and new bark grow over the swollen knot, hence it is necessary to chop through solid wood before the punky knot is reached. These are called blind conks. The swellings are caused by the living-wood tissue trying to grow over the knot where the conk is being formed, as shown in Plate 4, A, Plate 5, A, and Plate 3, B; and in many cases the appearance is accentuated by the growing conks actually pushing out the thick dead bark in a characteristic manner. The swelling resulting from the attempt to heal over a decayed knot is very marked when contrasted with the appearance of a normal sound knot grown over, as illustrated by Plates 4, B, and 5, B.

As the development of conks and swollen knots follows very closely the progress of decay in the heartwood, it is possible to pick out rather accurately the trees affected by red ring rot. It is extremely rare for a tree without conks or swollen knots to have red ring rot. No study has been made of the time required for the development of conks after infection, or of the rate of progress of decay in individual trees. Suri (*29, p. 328*) states that in deodar, *Cedrus deodara* Loud., infected with red ring rot, sporophores develop about 5 to 15 years after actual infection. An exact analysis of 170 Douglas fir trees with a total volume of 203,920 board feet and 38.4 per cent of loss from red ring rot showed that loss from

infections without conks or swollen knots comprised only 0.04 per cent, or an average loss of 3 board feet per infection (*4*, *p. 13*). When high up in a tree among the branches, swollen knots or conks are not readily seen with the naked eye, but if occurring there they do not make much difference in the accuracy of an estimate, since the scale of the top logs is insignificant in the total.

It is not only possible to pick out the decayed trees, but it is also feasible to judge with some accuracy the normal extent of red ring rot. Through careful study of a number of decayed trees it was found that the rot extended approximately 20 feet above or below the highest or lowest conk and approximately 9.5 feet (*4*, *p. 14*) above or below the highest or lowest swollen knot. These distances include the incipient decay and are close approximations. Naturally, individual examples varied considerably from the distances given, but these figures have been found to be a good average. They should be used only when there are several sporophores or swollen knots separated by a few feet. If there is a single conk or swollen knot or one compact group, only one 16-foot log, or 8 feet in each direction, should be culled. By studying felled trees and then watching infected logs through the mill, these limits can be set to fit any local conditions. Of course, when timber is felled and bucked it is possible to judge the extent of red ring rot much more exactly, since the ends of the logs can be examined for rot and the sides for swollen knots or conks.

It is difficult to estimate decay in fire-killed timber, but even there red ring rot can be detected. The dry, punky substance of the conks or swollen knots extending into the tree burns readily, while the surrounding bark is merely scorched and blackened, resulting in circular holes reaching 2 to 3 inches into the trunk—thoroughly reliable indications when their significance is understood. Of course it is impossible to tell whether the hole was formerly occupied by a swollen knot or by a conk.

Scars of any kind are rarely responsible for infections of red ring rot. The fungus almost invariably enters the tree through knots or branch stubs (*4*, *p. 7*, *8*).

RED-BROWN BUTT ROT

Red-brown butt rot, which also decays the roots, is caused by the velvet-top fungus, *Polyporus schweinitzii* Fr. The decay makes infected trees liable to wind throw, and it is not uncommon in the spring after the winter storms to see large Douglas firs broken off near the ground with the heartwood completely destroyed by this rot.

The incipient stage of red-brown butt rot is first evident as a faint yellowing or browning of the normal wood. This color intensifies, and the wood becomes soft. A hidden stage occurs for some distance beyond the incipient stage. While the incipient stage may extend over 8 feet beyond the advanced stage, the average is about 2 feet. In the advanced stage the wood is a pronounced red brown in color, completely broken down, as is shown in Plate 6, and crushes to a smooth powder between the fingers. In the shrinkage cracks are formed thin, crustlike layers of mycelium, which are easily mistaken for resin deposits. The rot is typically confined to the roots and

butt, commonly not extending beyond the first 16-foot log, although occasionally it may extend 40 feet up the trunk. Rarely it may be found higher, localized around the stub of a dead branch and not connected with the butt. On the end of a log the decay is approximately circular in outline, and the rot column as seen longitudinally is roughly cone shaped, tapering from the butt.

The following empirical rule for judging the longitudinal extent of the rot column in the butt log has been evolved from the dissection of a number of infected trees 200 years old and older. If the average diameter of the rot area on the butt of the log does not exceed 4 inches, the rot will extend up the log 1 foot for each inch in the diameter of the rot area. If the average diameter of the rot is from 5 to 10 inches, deduct 1 inch from that diameter and apply the same rule. If the diameter of the rot is more than 10 inches, deduct 1 inch for each additional 10 inches of that diameter. For example, in a log with a rot area 8 inches in diameter, the rot column should be figured as 7 feet long; if the average diameter is from 11 to 20 inches, deduct 2 inches; from 21 to 30 inches, deduct 3 inches; and 31 inches or over deduct 4 inches. It must be emphasized that there will be many exceptions to this rule, that it is not exact for individual logs, and can only be applied in scaling a number of defective logs.

The annual conks which develop most abundantly just after the fall rains begin are to be found issuing from an old wound on the butt of an infected tree or more commonly on the ground near by coming up from a decayed root. (Pl. 7.) On the tree the conk is a thin bracket, and frequently two or more brackets grow one above the other. On the ground, when viewed from above, the conk is circular in shape, sunken in the center, and tapering to a short, thick stalk. When fresh the upper surface is velvety, concentrically zoned, and reddish brown, with a light yellow-brown margin. The undersurface is dirty green and turns red brown when bruised. The conspicuous pores on the undersurface are irregular in shape. The substance of the conk is moist and cheesy. When old and dried, the conks become corky and have a deep red-brown or blackish brown color. Swollen and punky knots are not developed.

While the conks are a positive indication of red-brown butt rot, they are to be found only on a small minority of the infected trees. The next best clue to the presence of this decay is fire scars. The majority of fire-scarred trees become infected through the scar; therefore it is possible to judge the relative amount of decay by the number of such trees in the stand after the presence of conks has revealed the existence of this rot in the locality. Each fire-scarred tree can be considered as infected. Even though a scar has been healed over for a long time, it can often be detected by the difference in the appearance of the bark over the healed wound, which is hard to describe but not difficult to distinguish after a little experience. Swollen or churn butts usually indicate a fire scar or other wound long since healed. In cruising timber, culling 8 feet of the butt log usually is a sufficient allowance for this defect. If a butt scar is plainly visible, the rot can be considered as extending about 2 feet higher than the scar and the entire trunk culled from ground level to that height.

YELLOW-BROWN TOP ROT

Yellow-brown top rot, also known as brown pocket rot, caused by the rose-colored conk, *Fomes roseus* (Alb. and Schw.) Cke., occurs much more frequently on down, dead trees than it does on living ones. The first indication of the rot is a faint brownish or yellowish brown color, the outer limit of which is sometimes marked by a zone of greenish brown discoloration. The yellowish brown color deepens and the wood becomes soft. The incipient decay extends on an average about 3 feet beyond the advanced decay, but in exceptional cases it may extend 25 feet. The advanced decay is a yellow-brown crumbly rot with mycelium felts much less conspicuous than those of brown trunk rot. (Pl. 8, A.)

Normally the rot occurs in the upper part of the trunk or in the top beyond the merchantable limit; consequently, it is not economically so important as the others thus far discussed, for when it does destroy merchantable volume the lower quality top logs are the ones that suffer most. The rot column is roughly cylindrical, following the shape of the heartwood, and tapers conelike at the ends. Seen as a cross section at the ends of logs, the rot is circular in area.

The perennial, bracketlike conks, ranging up to 6 inches or so in width, are readily recognized by the delicate rose color and small regular pores of the undersurface. The upper surface is hard, rough, zoned, and black, as illustrated in Plate 8, A. No swollen or punk knots are associated with this decay.

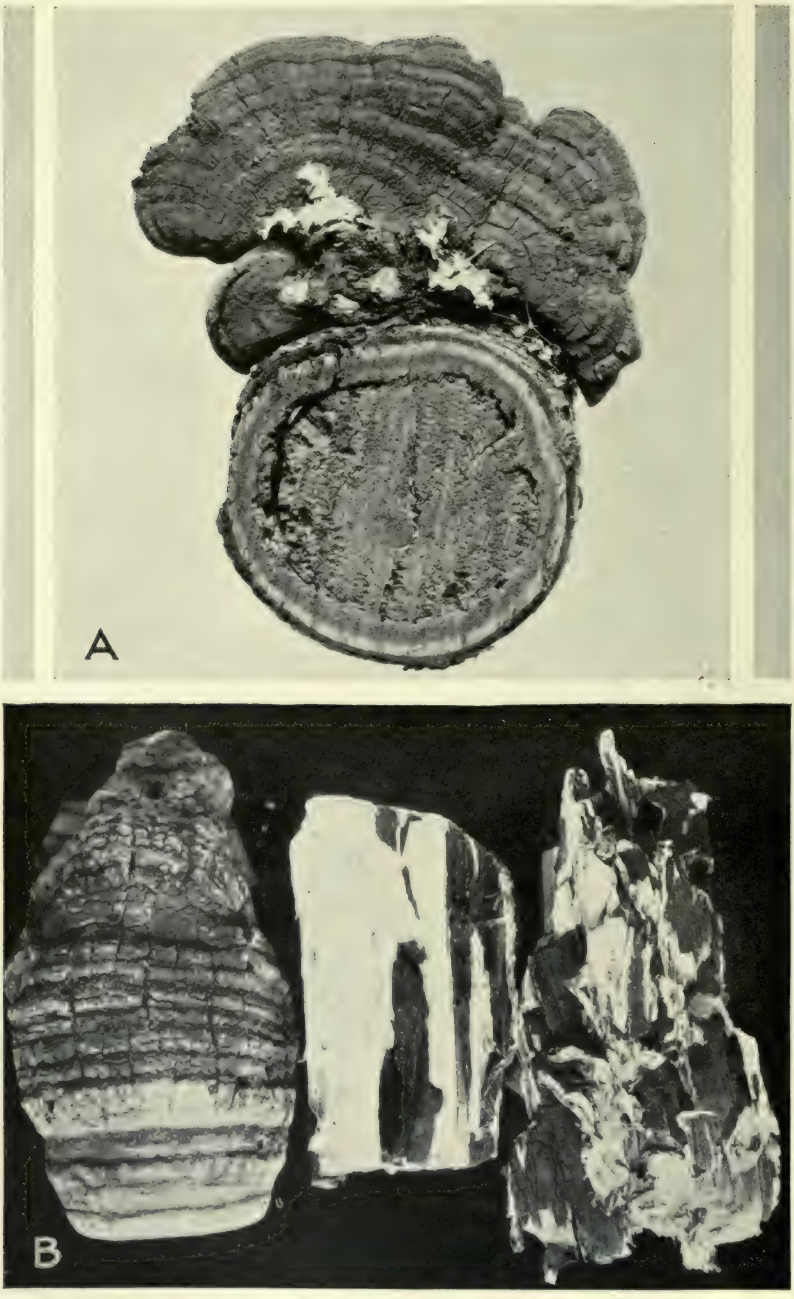
Yellow-brown top rot is very difficult to detect in standing timber. Although conks are not uncommon, they are so high up in the trees as to be easily overlooked, and are often completely hidden by the branches. The decay enters through the stubs of dead branches, dead tops, and wounds. Consequently, spike-topped trees are often infected.

BROWN TRUNK ROT

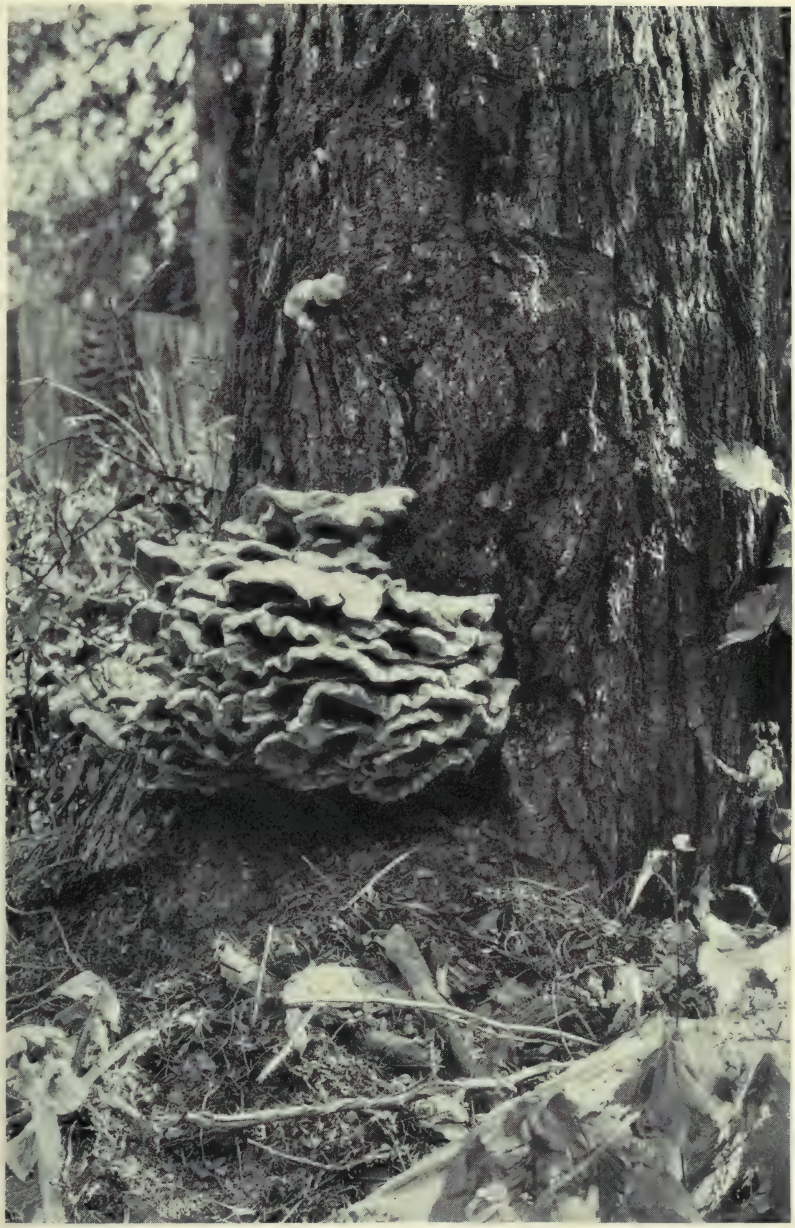
Brown trunk rot, also known as reddish brown rot and brown heartwood rot, is caused by the quinine fungus, *Fomes laricis* (Jacq.) Murr. The incipient rot is difficult to detect, since it first appears as an extremely faint, barely discernible brownish discoloration, scarcely contrasting with the normal reddish or orange-reddish color of the heartwood. It is preceded by a hidden stage which extends for several inches beyond the last visible discoloration. As the discoloration becomes more pronounced the wood becomes softer. Rarely the incipient stage appears to be indicated by a brilliant and intense purplish discoloration. It was found that incipient rot might extend 8.5 feet beyond the advanced decay, but the average was 3.6 feet. The wood is seriously weakened, even in the hidden stage of the rot.

In the advanced stage the wood is a brown mass, easily crumbled between the fingers. In shrinking it is more or less separated by cracks into irregular cubes. The cracks may be occupied by the conspicuous white mycelium felts. (Pl. 8, B.) These felts may completely fill large cracks or old wind-shakes, becoming a quarter of an inch thick, a foot or more wide, and several feet long. The decay is not confined to any particular portion of the bole. Where it runs out, the rot column is roughly conical, elsewhere it is more

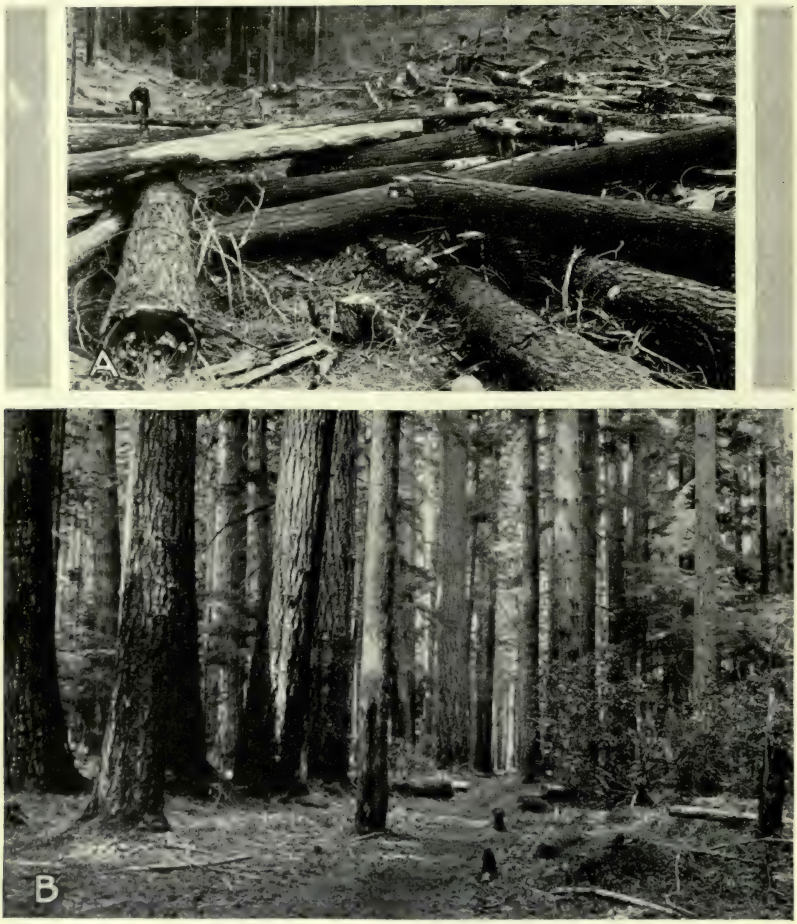
Conks of the velvet-top fungus, *Polyporus schweinitzii*, causing red-brown butt rot, on the ground near the base of an infected Douglas fir. Conks of this type vary from a few inches to a foot or more in diameter. (Photograph by Henry J. Rust)



A, Cross section of the decayed top from a living tree showing yellow-brown top rot caused by rose-colored conk, *Fomes roseus*, and the upper surface of a conk. Diameter inside bark of the section is 3.5 inches; B, decayed wood showing the white mycelium felts and an old chalky conk of brown trunk rot caused by the quinine fungus, *F. laricis*. (Photograph by E. E. Hubert)



Conks of brown cubical rot caused by the sulphur fungus, *Polyporus sulphureus*, on the butt of a dead white fir. (Photograph by Henry J. Rust)



A, Cull logs left in the woods. (Photograph by A. H. Hodgson); B, a greatly overmature, highly defective stand in the Douglas fir type. (Photograph by G. A. Bright.) Most of the defect in both cases is red ring rot caused by the ring-scale fungus, *Trametes pini*

Douglas firs left standing on a logging operation because presumably decayed. Later when a railroad right of way was cut through this stand a large percentage of merchantable volume was found

or less cylindrical. Seen on the ends of logs, the rot is usually somewhat circular in outline. In the advanced stage, shrinkage cracks are common along the annual rings and at right angles to them. Often these cracks are filled with the conspicuous mycelium felts.

The quinine fungus has large, whitish, perennial conks not common on living trees. They are either roughly hoof shaped or long and narrow. The substance of the conk is white, soft, and cheesy when young, and rather crumbly and chalky when old and dry. An old conk is depicted in Plate 8, B. The upper surface is chalky white or brownish, rough, and zoned, while the undersurface is white and has small pores. The conks issue through knots or old wounds. This decay forms no swollen or punky knots.

On the whole, it is not easy to judge brown trunk rot in standing timber. Since conks are developed only occasionally and only after decay has become extensive, a tree with a single conk must be considered unmerchantable. Broken tops are a common point of entrance for this decay; consequently, in a stand where the presence of conks has shown the decay to occur, broken-topped trees are probably infected. The trunks must be closely scanned for large broken-off branches in which the decay can be seen, for a branch with decayed heartwood indicates extensive rot in the trunk. Stands so much overmature that they are being replaced by hemlock are particularly subject to brown trunk rot. It seldom causes loss of consequence in other than very overmature timber.

BROWN CUBICAL ROT

The sulphur fungus, *Polyporus sulphureus* (Bull.) Fr., causes brown cubical rot, also called brown-checked wood rot. It is very difficult or impossible to distinguish this decay from brown trunk rot, although it usually starts in the butt of the tree, entering through an old wound, and normally does not extend above the lower half of the trunk. The conks, shown in Plate 9, are annual, mostly appearing in the summer or fall after a rain, and develop in clusters of large, flat shelves. They are soft, juicy, and cheesy, without any bitter taste. The upper surface is orange yellow and smooth; the smooth underside is a brilliant sulphur yellow. The pores are small. The conks are often partly eaten by rodents. When the conks dry up they commonly turn chalky white, or occasionally dirty yellow, and become brittle. No swollen or punky knots have been associated with this fungus.

PITTED SAP ROT

Pitted sap rot, which is very common in the sapwood of dead timber, occasionally occurs on the dead sapwood of basal wounds, particularly fire scars, on living trees. It is caused by the purple fungus, *Polystictus abietinus* (Dicks.) Fr. The rot first appears as a faint yellowish tan color and is accompanied by a softening of the wood. Next, the outlines of small white pockets become visible. In the advanced stage these pockets, which are elongated parallel to the grain, are at first filled with whitish fibers, but later become empty. They are separated by strips of apparently sound wood. The pitted sap rot is confined to the dead sapwood around scars, usually fire scars, on the butts of trees. It causes little loss, since

most of the affected sapwood forms part of the butt swell and slabs out in sawing.

The thin, bracket-shaped annual conks are small, with a grayish white, hairy, zoned upper surface, becoming dirty white with age. The purplish lower surface has conspicuous, irregular pores which sometimes become broken up so that the lower surface appears toothed. Aside from the conks, there are no reliable indications of this rot except the presence of fire scars. It is not found so often on mature or overmature trees as on trees in second-growth stands swept by ground fires.

SPONGY SAP ROT

The conifer root fungus, *Fomes annosus* (Fr.) Cke., causes spongy sap rot. The incipient rot is indicated by a reddish or violet color of the affected wood. The advanced decay is characterized by small white cellulose pockets following the grain of the wood and similar to the pockets of red ring rot. These pockets frequently run together, resulting in masses of moist, spongy, white fibers. Throughout the spongy masses, or in the pockets, occasional black flecks can be seen. The rot is confined to the roots and butt of the tree, rarely extending more than 2 to 4 feet high. It may occur in either heartwood or sapwood.

The perennial conks vary from bracketlike to almost crustlike form. The upper surface is zoned and of a gray-brown color. The undersurface is yellowish white and has numerous small pores. The conks are found in the root crotches or on exposed roots, often partially covered by duff; hence they are easily overlooked.

ENTRANCE OF ROT

In a previous study (*4, p. 7–10*) it was shown that knots or branch stubs were the means of entrance for 89.2 per cent of the decay by board-foot volume, while dead tops and scars of various kinds accounted for most of the remainder. Among the scars, those caused by fire were responsible for 4.2 per cent of the total rot, and are the only type of scar that can be prevented to some degree. This can be done by more efficient fire protection. It was concluded that reducing the scars caused by controllable mechanical injuries could cause little reduction in the amount of rot.

The present study, in which it was not possible to dissect the trees, largely corroborated the previous conclusions. However, it becomes increasingly apparent that fire scars, which can be controlled to some extent, are of more importance than is indicated by the actual volume of decay for which they are responsible, for the decay is largely butt rot, destroying part of the valuable butt log, which becomes relatively more valuable as the size of the timber decreases. Butt rot also predisposes trees to windfall, particularly if it affects their roots.

IMPORTANCE OF ROTS

The loss through decay amounted to 16.99 per cent of the board feet measured, while the loss from all other causes combined was only 10.78 per cent, as can be seen from Table 2. Red ring rot is by far the most important of the various decays; this is shown more clearly by Table 8, in which the total percentage of rot in board and cubic

feet in Table 2 is taken as 100 per cent. This shows that red ring rot comprised 80.8 per cent of all the decay in board feet, brown trunk rot coming next with only 8.6 per cent, closely followed by red-brown butt rot with 6.2 per cent and yellow-brown top rot with 4.1 per cent, while pitted sap rot, spongy sap rot, brown cubical rot, and unknown rots were practically negligible, so that subsequently in this bulletin they will be combined and listed as " other rots."

TABLE 8.—*Relative importance of the different rots in Douglas fir*

Type of rot	Total rot in—	
	Board-foot volume	Cubic-foot volume
	Per cent	*Per cent*
Red ring rot (Trametes pini)	80.8	79.2
Brown trunk rot (Fomes laricis)	8.6	8.4
Red-brown butt rot (Polyporus schweinitzii)	6.2	7.9
Yellow-brown top rot (Fomes roseus)	4.1	4.0
Pitted sap rot (Polystictus abietinus)	.1	.2
Spongy sap rot (Fomes annosus)	.1	.1
Brown cubical rot (Polyporus sulphureus)	0	Trace.[1]
Unknown rots	.1	.1

[1] Trace means that percentage of rot was less than 0.01.

In scaling out decay in board feet, the Forest Service regulations for this region were followed. All logs decayed 66⅔ per cent or more were classed as totally unmerchantable. On the other hand, the actual cubic-foot volume of rot was figured, and the remaining volume in the section, no matter how small, was considered sound, which accounts for the much higher percentage of decay in board-foot volume than in cubic-foot volume. In other words, the cubic-foot figure is an exact measure of the actual volume of decayed wood, but the board-foot figure is a measure of the volume rendered unmerchantable by decay, according to present Forest Service scaling practice. In neither board-foot nor cubic-foot measurement was the incipient decay of red ring rot included with the volume of decay, because wood so affected is quite satisfactory for lower grades of lumber. Although there is an appreciable loss in quality by degrading because of incipient red ring rot, no study has been made of the amount of this loss. For the other rots, wood in the incipient stage of decay was included in the volume of decayed wood.

The distribution of the four important rots in the different plots is given in Table 9, in which the plots have been grouped by sites and arranged chronologically by ages. The greatest loss through decay amounted to 54.8 per cent of the board-feet volume on plot 38, an enormous loss when it is remembered that this plot represents a stand covering hundreds of acres. Plate 10, A, which while not a photograph taken on plot 38, was taken on another portion of the same logging operation and in a stand of the same character, illustrates the large number of cull logs in such a highly defective stand. Plate 10, B, represents this type of stand before logging. The highest loss through red ring rot was 50.7 per cent in the same plot; through butt rot, 4.1 per cent, in plot 9; through top rot, 6 per cent, in plot 36; and through trunk rot, 9.7 per cent, in plot 37. The loss caused by all other rots combined was appreciable in only two

plots, Nos. 24 and 5, being 0.7 per cent in each case. In plot 5, supporting a stand which had suffered from a ground fire which had fire-scarred many trees, pitted sap rot was responsible. In plot 24, spongy rot was the cause. Seldom did loss from any of the other decays exceed that from red ring rot.

TABLE 9.—*Rot in Douglas firs of merchantable size by plots on Sites I, II, and III, based on gross board-foot and cubic-foot volumes per acre*

SITE I

Plot No.	Average age	Percentage of rot [1] in—											
		Board-foot volume						Cubic-foot volume					
		Red ring rot	Butt rot	Top rot	Trunk rot	Other rot	Total rot	Red ring rot	Butt rot	Top rot	Trunk rot	Other rot	Total rot
1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Years												
15	204	0	0.1	Tr.	Tr.	0	0.2	0	0.1	Tr.	Tr.	0	0.1
10	232	6.6	.1	0	0.3	0	7.0	3.5	.1	0	0.1	0	3.7
18	333	7.2	.9	1.2	2.9	0	12.2	4.6	.7	.7	1.7	0	7.7
21	340	27.6	.6	0	1.1	.1	29.4	15.8	.6	0	.6	.2	17.2
28	412	24.0	3.0	1.2	1.8	Tr.	30.0	12.4	2.6	.8	1.1	Tr.	16.9
Total or average	304	13.1	.9	.5	1.2	Tr.	15.7	7.3	.8	.3	.7	.04	9.1

SITE II

11	64	0	0	0	0	Tr.	Tr.	0	Tr.	0	0	Tr.	Tr.
32	94	.4	.5	Tr.	0	0	0.9	.3	0.3	Tr.	0	0	0.6
6	112	.1	.1	Tr.	0	0	.2	.1	.1	Tr.	0	0	.2
33	122	1.7	.3	.9	0	0	2.9	.7	.2	.4	0	0	1.3
8	158	3.5	.1	.1	.6	Tr.	4.3	1.5	.1	.1	.4	Tr.	2.1
26	183	10.7	.6	.1	3.1	Tr.	14.5	5.7	.4	Tr.	1.2	Tr.	7.3
14	197	4.1	Tr.	0	0	0	4.1	2.4	Tr.	0	0	0	2.4
7	198	5.3	Tr.	.6	.9	0	6.8	3.0	Tr.	.2	.4	0	3.6
12	237	16.5	.6	.2	.4	.2	17.9	9.6	.5	.1	.2	.2	10.6
16	238	0	1.2	.1	.3	0	1.6	0	.7	.1	.2	0	1.0
27	243	7.6	.3	Tr.	.1	0	8.0	4.4	.2	Tr.	.1	0	4.7
35	245	3.4	0	.1	0	0	3.5	1.8	0	.1	0	0	1.9
25	245	27.5	.5	.2	1.6	0	29.8	15.7	.3	.1	.8	0	16.9
17	245	0	.1	0	.1	0	.2	0	.1	0	Tr.	0	.1
36	258	13.1	.6	6.0	2.6	.2	22.5	6.2	.5	3.5	1.3	.1	11.6
30	289	1.9	1.1	.5	0	0	3.5	1.2	.7	.4	0	0	2.3
24	309	13.2	.7	0	1.4	.7	16.0	7.0	.5	0	.7	.3	8.5
22	316	23.7	.1	.1	Tr.	.1	24.0	13.8	.1	Tr.	Tr.	Tr.	13.9
38	319	50.7	.5	2.5	1.1	0	54.8	29.9	.3	1.3	.7	0	32.2
37	322	33.4	1.6	.8	9.7	Tr.	45.5	18.9	1.7	.5	5.6	.1	26.8
31	333	21.7	.3	.1	.2	0	22.3	13.2	.2	.1	.1	0	13.6
13	345	6.6	1.4	Tr.	5.7	0	13.7	3.7	1.1	Tr.	3.3	0	8.1
20	349	9.5	2.1	.6	.3	0	12.5	5.2	1.3	.3	.2	0	7.0
34	383	4.7	1.5	3.9	1.9	0	12.0	3.1	1.2	2.1	1.3	0	7.7
23	404	25.2	1.7	1.1	2.9	0	30.9	13.9	1.1	.6	1.8	.1	17.5
19	559	.8	3.1	3.2	1.1	0	8.2	.4	2.1	2.0	.6	0	5.1
Total or average	260	11.0	.7	.8	1.3	Tr.	13.8	6.2	.5	.5	.7	Tr.	7.9

SITE III

4	66	0	0	0	0	0	0	0	0	0	0	0	0
1	103	0	1.8	.1	1.2	.1	3.2	0	.9	Tr.	.4	Tr.	1.3
2	114	4.0	2.1	.1	2.5	0	8.7	2.0	.8	Tr.	1.0	0	3.8
5	116	.5	.7	.2	.2	.7	2.3	.3	.4	.1	.1	.7	1.6
29	145	5.6	.6	0	0	0	6.2	3.0	.4	Tr.	0	Tr.	3.4
3	149	3.6	1.2	Tr.	.5	.1	5.4	2.4	.6	Tr.	.2	.1	3.3
9	400	.6	4.1	.2	.2	.1	5.2	.4	2.7	.1	.1	.1	3.4
Total or average	156	2.0	1.5	.1	.7	.1	4.4	1.1	.8	Tr.	.3	.1	2.3

[1] Trace (Tr.) means that percentage of rot was less than 0.01.

AGE AT WHICH INFECTION OCCURS

In this study it was, of course, impossible to determine the earliest age at which Douglas fir became infected with any decay, since for this purpose it would have been necessary not only to fell but to split open a large number of young trees. Where the trees are cut into log lengths but not opened up farther, it is not possible to find very small infections. Table 10 shows the youngest tree with measurable loss caused by each type of rot. From this it can be seen that decay may appear in individual trees rather early in the life of the stand. The first measurable loss was caused by butt rot in a tree 73 years old, and the original data showed that butt rot was first found in a 63-year-old tree, though in negligible quantity. Top rot and red ring rot both appeared in trees less than 100 years old, but trunk rot caused loss first in a 146-year-old tree. It was apparent throughout the study that trunk rot did not appear until later in the life of the stand than the other three decays.

TABLE 10.—*Youngest trees on the plots with actual loss in board-foot volume caused by the important rots*

Age (years)	Diameter breast high	Height	Gross volume of tree in—		Rot in—		Type of rot
			Board feet	Cubic feet	Board-foot volume	Cubic-foot volume	
1	2	3	4	5	6	7	8
	Inches	*Feet*			*Per cent*	*Per cent*	
73	20.0	120.1	370	87	5.4	3.2	Butt rot.
76	21.2	137.3	670	126	1.5	.4	Top rot.
91	8.0	61.1	20	5	100.0	61.4	Red ring rot.
146	35.4	150.2	1,250	240	12.8	4.3	Trunk rot.

Red ring rot may appear in individual trees much younger than those found infected on these plots. Near Salem, Oreg., extensive decay from this cause was found in a small suppressed Douglas fir [5] 4 inches in diameter at breast height and 24 years old at stump height, 1 foot above the ground, or 27 years old at ground level, as calculated by means of a seedling height curve. The tree had died from the effects of suppression not more than two years prior to its inspection. The heartwood was decayed throughout its length. Four small sporophores or conks occurred along the bole. Since decay had progressed so far before the tree died at an age of 27 years, infection must have occurred some years previously.

RELATION OF ROT TO AGE AND SITE

From the practical standpoint the age at which decay begins in individual trees is of little consequence, but the age at which the stand becomes appreciably affected by decay, and the rate at which loss by decay increases during the life of the stand are of paramount

[5] Data on this tree furnished by T. W. Childs.

importance to proper management. It is well known that young stands are practically free from decay and that old stands may be heavily infected, but beyond this vague generality no exact information has been available. Furthermore, nothing has been known concerning the influence of site on decay. Theoretically, the most defective timber would be expected to occur on the poorest site, where growth is slowest, since Meinecke (*17*, *p. 47*) has shown that suppressed trees of white fir, *Abies concolor* (Gord.) A. Murray, are subject to decay at an earlier age than dominants; and it has been found in the case of incense cedar, *Libocedrus decurrens* Torr., that the slower growing trees outside the optimum range suffer more from decay than the faster growing trees within the optimum (*2*, *p. 28*).

Decay is shown in Table 9 for the plots arranged chronologically by ages for Sites I, II, and III. On Site I it can be seen that the percentage of decay increases very definitely with increasing age. This is also true for Site II, but is not so apparent, because of the great variation in individual plots. It is quite evident that stands may attain a considerable age with little or no loss from decay—for example, plot 16, age 238 years, with 1.6 per cent of rot in the board-foot volume; plot 17, age 245 years, with 0.2 per cent of rot; and plot 30, age 289 years, with 3.5 per cent. On the other hand, loss at the same ages may be heavy, as is shown by plot 25, age 245 years, with 29.8 per cent of rot in the board-foot volume. There is no explanation of why certain stands may attain old age with little rot. All stands have ample opportunity for infection, since red ring rot, which produces conks so abundantly, is present everywhere. Plot 9, age 400 years, is a good example. It had a loss of only 5.2 per cent from decay, 4.1 per cent of the loss being caused by butt rot and only 0.6 per cent by red ring rot. Nevertheless this stand was in a locality where heavy losses from red ring rot were the rule, and it was situated close to highly defective stands. Of two old trees standing side by side with apparently equal chances to become infected, one may be sound and the other badly decayed. Whether the difference is due to mere chance, or to one tree possessing some inherent resistance to wood-destroying fungi, is problematical. When this speculation is carried on to consideration of whole stands the question becomes even more complex.

In order to bring out more clearly the relation of decay to age on Site II the plots are grouped in 50-year age classes in Table 11. This demonstrates the decided increase in the amount of decay up to and including the 301 to 350 year age class. Beyond that age class the data become irregular, owing to the fact that each class is based on only one plot; and, as has been pointed out before, occasional stands may reach old age with very little loss from rot. Probably there is some further explanation for the low figure of 8.2 per cent of decay in board-foot volume in the 559-year-old plot representing the last age class. It is known that if a Douglas fir stand is allowed to round out its life undisturbed by fire, lumbering, or any other destructive force, as the older trees die their places are taken mostly by western hemlock, *Tsuga heterophylla*, so that ultimately the final stand becomes predominantly hemlock. This breaking up may begin as early as after 350 years, and a Douglas fir stand more than 600 years old which has not broken up completely is rare. It

is reasonable to believe that the majority of the first trees to go would be badly decayed individuals, which, if nothing else, are more subject to wind throw than are sound trees. Thus, when a stand is breaking up there is a strong possibility that the percentage of decay in the Douglas firs might actually decrease, since the dropping out of the decadent individuals might more than offset the increase in decay among the survivors. This 559-year-old plot represented such a stand, and by referring to Table 1 it is seen that Douglas fir of merchantable size comprised only 72.7 per cent of the entire stand measured in board feet, and the remainder was young western hemlock. It was not feasible, however, to study any more plots representative of such stands and to determine whether the percentage of decay actually does decrease with extreme age in the Douglas fir.

TABLE 11.—*Rot in Douglas firs of merchantable size by plots on Site II, grouped in 50-year age classes, based on gross board-foot and cubic-foot volumes per acre*

Age class (years)	Average age	Percentage of rot [1] in—												Plots (basis)
		Board-foot volume						Cubic-foot volume						
		Red ring rot	Butt rot	Top rot	Trunk rot	Other rot	Total rot	Red ring rot	Butt rot	Top rot	Trunk rot	Other rot	Total rot	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Years													*Number*
51 to 100	79	0.2	0.3	Tr.	0	Tr.	0.5	0.2	0.2	Tr.	0	Tr.	0.4	2
101 to 150	117	.9	.2	0.5	0	0	1.6	.4	.2	0.2	0	0	.8	2
151 to 200	184	5.9	.2	.2	1.2	Tr.	7.5	3.2	.1	.1	0.5	Tr.	3.9	4
201 to 250	242	9.2	.5	.1	.4	Tr.	10.2	5.3	.3	.1	.2	Tr.	5.9	6
251 to 300	274	7.5	.9	3.3	1.3	.1	13.1	3.7	.6	2	.7	Tr.	7	2
301 to 350	328	22.7	1	.6	2.3	.1	26.7	13.1	.7	.3	1.5	0.1	15.7	7
351 to 400	383	4.7	1.5	3.9	1.9	0	12	3.1	1.2	2.1	1.3	0	7.7	1
401 to 450	404	25.2	1.7	1.1	2.9	0	30.9	13.9	1.1	.6	1.8	.1	17.5	1
551 to 600	559	.8	3.1	3.2	1.1	0	8.2	.4	2.1	2	.6	0	5.1	1
Total or average.	260	11	.7	.8	1.3	Tr.	13.8	6.2	.5	.5	.7	Tr.	7.9	26

[1] Trace (Tr.) means that percentage of rot was less than 0.01.

In order to provide an adequate means of determining the relation between age and decay, and to evaluate properly the relation between site and decay, the data for Site II in Table 11 are shown for both board and cubic feet in Figure 9. The numbers of plots on Sites I and III were not sufficient to warrant the presentation of curves for these sites. The reason for the small numbers of plots on Sites I and III is obvious. Site I, representing the best and usually the most accessible stands of Douglas fir, had been largely cut off, even on private holdings, at the time this study was made, while the poorer stands on Site III had not been reached to any extent, so that most of the logging was under way on Site II.

In addition to knowing the average conditions of decay on a site, it is also essential to know the worst conditions that may be encountered. For this reason a curve of maximum decay was drawn, based on the most highly defective plots, all of which were on Site II; that is, plot 26 with 14.5 per cent of decay in board-foot volume

at 183 years, plot 25 with 29.8 per cent at 245 years, and plot 38 with 54.8 per cent at 319 years. This is the curve marked maximum.

The curves for percentage of average decay in board and cubic foot volumes in Figure 9 have been carried to 450 years, but the curves for maximum decay have been extended only 350 years, since there is no guide for them in the older ages. The average age of the

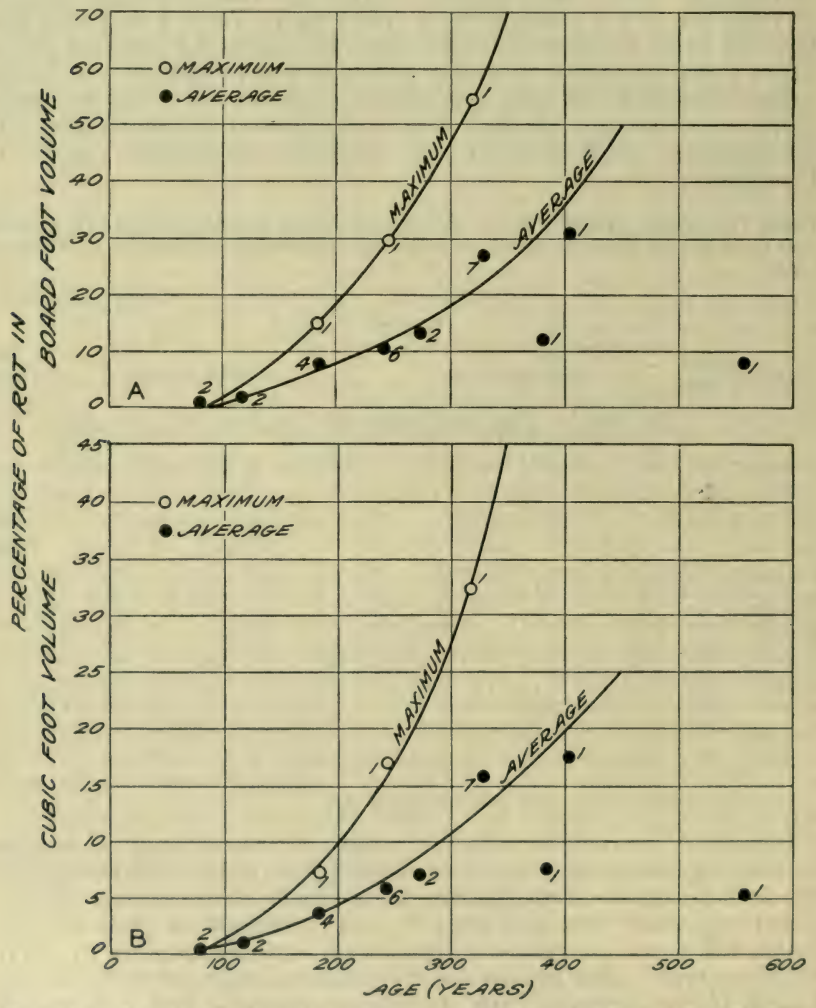


FIGURE 9.—Percentage of rot in relation to age of Douglas firs of merchantable size on Site II based on gross volume per acre: A, Board feet (Scribner Decimal C rule); B, cubic feet

oldest plot is 559 years, but there are no plots between 404 and 559 years. Furthermore, as was pointed out, the Douglas fir stand as represented by this 559-year-old plot on Site II had already broken up to a considerable extent, which fact might result in lowering the percentage of decay, but no other stands of this character were studied in detail, so it was impossible to consider the influence of

this one plot on the curve. Comparing the curves for the average percentage of rot on Site II with the data given in Table 9 for the percentage of rot for the plots on Site I, it is seen that stands of which the three youngest plots are representative have less decay than average stands on Site II at the same age. Unfortunately the youngest plot on Site I was 204 years old, so that no comparison can be made for younger ages. Comparing in the same way the percentage of rot for the plots on Site III, it shows that these plots have more decay than average stands of the same age on Site II up to 150 years. It is the cubic-foot figures that are most important, since they are an exact, not a relative, measure of the volume of decayed wood. There is only one plot on Site III older than 150 years, and it has a low percentage of rot. These fragmentary data are not sufficient to permit of a definite conclusion as to the incidence of decay in relation to site, although they seem to indicate that in younger ages rot is of least consequence on Site I and is more serious on Site III than on Site II. For reasons previously given there are no plots on Sites IV and V. It is significant that the youngest trees with actual loss in board-foot volume from the four principal rots, as shown in Table 10, were all on Site III. Möller (*20, p. 200*), who has extensively investigated red ring rot in stands of Scotch pine, *Pinus sylvestris* L., in Germany, concludes that there is no significant difference in the amount of decay on the five sites.

From these curves the correlation of the increase in decay and the increase in age stands forth clearly; but while this in itself is important, the relation between the increment in gross volume and the increment in decay is more significant. In other words, at what age does the stand decay as fast as it grows? The answer to this has been worked out in Tables 12 and 13 for Site II in board and cubic feet by 50-year periods. A word of explanation as to the derivation of these tables should be given. In Table 12, for example, the gross volume per acre in board feet at 50-year intervals is read from the volume curve in Figure 3. The gross increment per acre in column 4 is obtained by subtraction of the gross volume in column 2 by 50-year periods. The percentage of rot in column 6 is read from the curve of average rot percentage for Site II in Figure 9. The volume of rot per acre in column 3 is secured by multiplying the gross volume per acre in column 2 by the corresponding percentage of rot in column 6. The rot increment per acre is again a simple subtraction. Now, by comparing gross increment per acre with rot increment, it is seen that the former keeps well ahead of the latter until somewhere between 300 and 350 years, when decay increment equals gross increment, and from then on exceeds it. That is, from that time on the Douglas fir stand decays faster than it grows. Curves showing rot increment and gross increment with relation to age demonstrate that rot increment equals gross increment at approximately 300 years, as stated in footnote 1 of Table 12. For the sake of brevity these curves are omitted.

TABLE 12.—*Periodic increment in average gross volume and average rot volume per acre for Douglas fir on Site II*

BOARD FEET [1]

Age (years)	Gross volume	Rot volume	Gross increment	Rot increment	Percentage of rot
1	2	3	4	5	6
50	20,000	0	20,000	0	0
100	69,000	690	49,000	690	1
150	110,000	4,400	41,000	3,710	4
200	136,000	10,470	26,000	6,070	7.7
250	158,000	19,120	22,000	8,650	12.1
300	174,000	31,500	16,000	12,380	18.1
350	186,000	47,620	12,000	16,120	25.6
400	196,000	69,970	10,000	22,350	35.7
450	203,000	101,500	7,000	31,530	50.0

CUBIC FEET [2]

50	3,900	0	3,900	0	0
100	12,200	70	8,300	70	.6
150	17,500	380	5,300	310	2.2
200	21,100	930	3,600	550	4.4
250	23,850	1,760	2,750	830	7.4
300	26,000	2,830	2,150	1,070	10.9
350	27,700	4,160	1,700	1,330	15.0
400	28,900	5,690	1,200	1,530	19.7
450	29,600	7,400	700	1,710	25.0

[1] Rot increment equals gross increment at approximately 300 years.
[2] Rot increment equals gross increment at approximately 345 years.

TABLE 13.—*Periodic increment in average gross volume and maximum rot volume per acre for Douglas fir on Site II*

BOARD FEET [1]

Age (years)	Gross volume	Rot volume	Gross increment	Rot increment	Percentage of rot
1	2	3	4	5	6
50	20,000	0	20,000	0	0
100	69,000	1,100	49,000	1,100	1.6
150	110,000	9,460	41,000	8,360	8.6
200	136,000	24,620	26,000	15,160	18.1
250	158,000	48,510	22,000	23,890	30.7
300	174,000	81,610	16,000	33,100	46.9
350	186,000	130,200	12,000	48,590	70.0

CUBIC FEET [2]

50	3,900	0	3,900	0	0
100	12,200	150	8,300	150	1.2
150	17,500	820	5,300	670	4.7
200	21,100	2,070	3,600	1,250	9.8
250	23,850	3,940	2,750	1,870	16.5
300	26,000	6,990	2,150	3,050	26.9
350	27,700	12,460	1,700	5,470	45.0

[1] Rot increment equals gross increment at approximately 215 years.
[2] Rot increment equals gross increment at approximately 250 years.

From Tables 12 and 13 it is evident that under the very worst conditions, as shown by Table 13, which is based on the maximum increase in decay found on Site II, Douglas fir stands on Site II will not decay faster than they grow in board feet until the age of

about 215 years is reached, and under average conditions until they are about 300 years of age. Of course, when measuring volumes in cubic feet this point is attained considerably later in the life of the stand. This means that in the future Douglas fir can be grown on Site II with little resultant loss from decay, since it is not likely that the rotation will exceed 110 years on the national forests, except for occasional stands, and it probably will fall several decades lower on private lands as a rule. At 110 years the maximum loss shown in Figure 9 is 2.8 per cent, based on gross board-foot volume per acre. The large amount of decay in Douglas fir at present is confined to badly overmature stands, an example of which is pictured in Plate 10, B, and is the accumulated result of centuries of unregulated growth.

The idea that decay in Douglas fir works very rapidly is prevalent throughout this region. In fact, it has been suggested that the loss might mount as high as 5 per cent a year, and 2 or 3 per cent is not an uncommon estimate (*26*). Tables 12 and 13 give no support to such estimates. For Site II with maximum rot the most rapid increase in decay amounts to 23.1 per cent of the gross volume in board feet between 300 and 350 years, or 0.46 per cent a year. And for Site II with average rot it is only 0.29 per cent a year between 400 and 450 years. Of course, when a stand reaches the age at which it breaks up, the rate of loss is undoubtedly more rapid than anything shown by these figures, but under such conditions sound or relatively sound trees drop out, along with the highly defective, so that the loss can not all be charged against decay. It was not possible to study enough stands in the process of breaking up to determine the rate of loss in volume of the Douglas fir during such a period.

In forestry literature dealing with regulation and yield, there is found the statement—it might almost be termed an axiom—that in virgin mature and overmature stands decay (or deterioration may be the term used) is balanced by growth. This aphorism has never been supported by exact data. To anyone familiar with the Douglas fir stands of the Pacific Northwest, observation would indicate that in many overmature stands decay alone, to say nothing of the continual dropping out of large individual trees, would result in a net loss in increment for a considerable period. In the case of Douglas fir stands, not only the Douglas firs but also the associated species must be included in calculations of increment.

Accordingly, in Table 14 the gross volume per acre of trees of all species 12 inches and larger in diameter breast high for the Site II plots has been computed in board and cubic feet and averaged by 50-year age classes. The percentage of rot in board and cubic feet is also given. The average age for each plot was necessarily taken as the average age of the felled Douglas firs. The volumes per acre in board and cubic feet were then curved on age in Figure 10, and the percentages of rot were curved in the same way in Figure 11. From these curves, Table 15 was constructed, which shows the gross increment and rot increment by 50-year periods.

TABLE 14.—*Gross volume per acre in board and cubic feet and percentage of rot for trees of all species 12 inches and larger in diameter breast high, by plots on Site II, grouped in 50-year age classes*

Age class (years)	Average age	Gross volume in—		Rot in—		Plots (basis)
		Board feet	Cubic feet	Board-foot volume	Cubic-foot volume	
1	2	3	4	5	6	7
	Years			*Per cent*	*Per cent*	*Number*
51 to 100	79	50,210	10,051	0.4	0.3	2
101 to 150	117	93,750	15,808	1.4	.6	2
151 to 200	184	145,530	23,226	7.4	3.8	4
201 to 250	242	145,470	22,931	10.0	5.7	6
251 to 300	273	185,720	28,956	12.6	6.7	2
301 to 350	328	203,140	30,756	26.6	15.4	7
351 to 400	383	92,530	14,606	11.2	6.8	1
401 to 450	404	184,570	27,664	29.7	16.6	1
551 to 600	559	156,250	24,662	5.9	3.5	1

TABLE 15.—*Periodic increment in average gross volume and average rot volume per acre for trees of all species, 12 inches and larger in diameter breast high, on Site II*

BOARD FEET [1]

Age (years)	Gross volume	Rot volume	Gross increment	Rot increment	Percentage of rot
1	2	3	4	5	6
50	21,500	0	21,500	0	0
100	73,000	730	51,500	730	1.0
150	113,500	3,630	40,500	2,900	3.2
200	140,500	9,980	27,000	6,350	7.1
250	161,500	18,730	21,000	8,750	11.6
300	177,000	31,000	15,500	12,270	17.5
350	190,000	46,930	13,000	15,930	24.7
400	200,000	67,600	10,000	20,670	33.8
450	208,000	92,770	8,000	25,170	44.6

CUBIC FEET [2]

50	4,000	0	4,000	0	0
100	12,800	50	8,800	50	.4
150	18,000	340	5,200	290	1.9
200	21,900	880	3,900	540	4.0
250	25,100	1,710	3,200	830	6.8
300	27,500	2,780	2,400	1,070	10.1
350	29,300	4,160	1,800	1,380	14.2
400	30,700	5,650	1,400	1,490	18.4
450	31,600	7,170	900	1,520	22.7

[1] Rot increment equals gross increment at approximately 300 years.
[2] Rot increment equals gross increment at approximately 360 years.

Comparing columns 4 and 5 based on board-foot volume in Table 15, it is seen that periodic rot increment is less than periodic gross increment up to and including 300 years, but at 350 years periodic rot increment exceeds periodic gross increment, which means that rot increment equals gross increment at some time in the 300 to 350 year period. The curves for rot increment and gross increment over age as explained on page 37 show that the change occurs at 300 years. For cubic feet (Table 15) the change takes place at 360 years. From 300 years on in board-foot volume and from 360 years on in cubic-foot volume the stand shows a net loss in increment owing to

rot. There were not enough plots in the age classes from 400 to 600 years to show the marked decline in gross increment which must occur because of the breaking up of the Douglas fir stand, although the tendency to flatten out, shown at the upper ends of the board and cubic-foot volume curves, indicate this. Data on the older age classes would undoubtedly reveal that for a period of 100 to 200 years or more there would be a heavy loss in net increment. The data show such a loss from decay, which would be supplemented by the dropping out of large trees as the stand breaks up. Finally, the

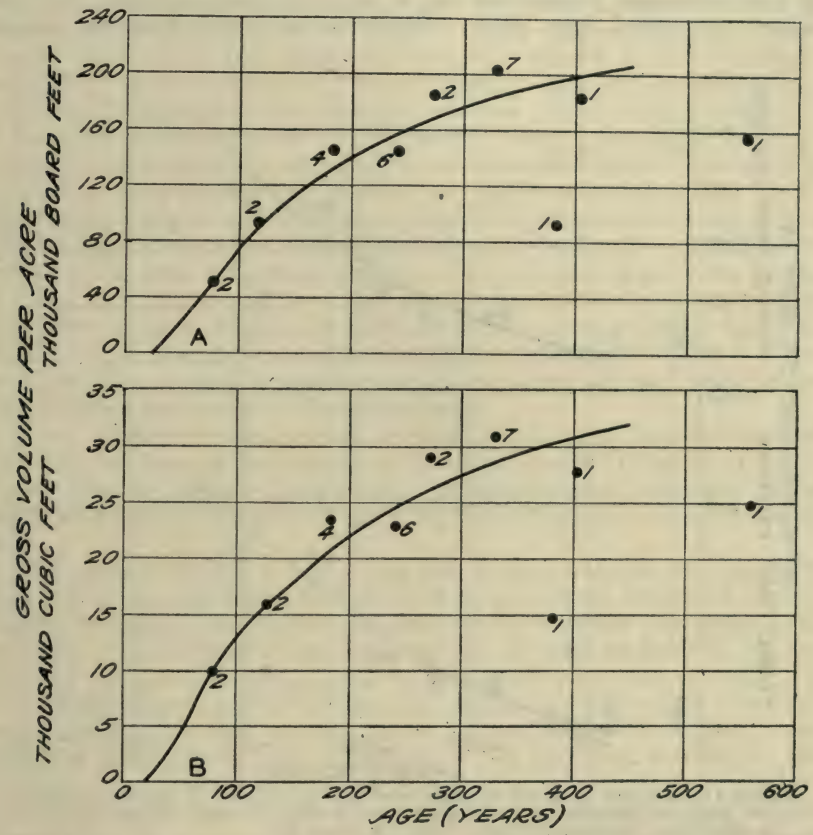


FIGURE 10.—Gross volume per acre of trees of all species, 12 inches and larger in diameter breast high, in relation to age on Site II; A, Board feet (Scribner Decimal C rule); B, cubic feet

net loss in increment would again disappear, and there would be a net gain as the younger trees of western hemlock, Douglas fir, and associated species acting as replacements attained sufficient size. During the period of net loss in increment from decay, as shown by Table 15, this loss is actually more serious than it appears. While rot is largely destroying high-quality wood in the large trees, the volume partly replacing this loss is mostly in young trees, which because of their many limbs for a long period produce only low-quality wood. Logs of grades Nos. 1 and 2 are being replaced by logs of grade No. 3, which during 1929 in the Columbia River region

had an average value of $12 per thousand board feet, $3.50 less per thousand than No. 2 logs and $10 less than No. 1. Furthermore, the data in Table 15 are based on all trees 12 inches and larger in diameter breast high, but it is very rare that cutting to such a low diameter limit is carried on anywhere in the Douglas fir region; and in fact on most logging operations in large mature and overmature timber, no trees less than 20 inches in diameter breast high are felled. Those occasional operations with a market for pulpwood do cut small western hemlocks. On the whole, however, the loss in net increment because of rot is actually more serious than the figures presented here show. There is no doubt that for virgin

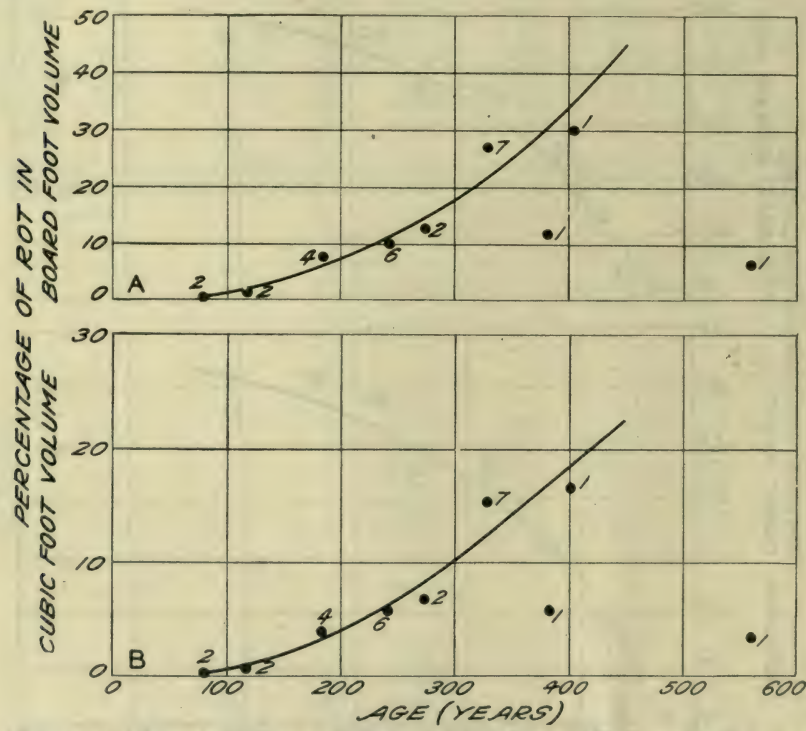


FIGURE 11.—Percentage of rot in relation to age of trees of all species 12 inches and larger in diameter breast high on Site II based on gross volume per acre: A, Board feet (Scribner Decimal C rule); B, cubic feet

overmature Douglas fir stands in the majority of cases the statement that growth increment balances decay increment—however comforting to owners of overmature defective timber—is untenable. Exceptional stands may remain relatively sound throughout their life.

RELATION OF ROT TO VIGOR OF TREES

Studies on incense cedar (*2, p. 28*) have shown that in the younger age classes, slow-growing trees are more subject to rot than fast-growing ones. Meinecke (*17, p. 47; 18, p. 18*) points out that decay of consequence begins at an earlier age in suppressed trees than it does in dominant trees of white fir affected by the Indian-paint

fungus, *Echinodontium tinctorium* Ell. and Ev., and of aspen, *Populus tremuloides* Michx., in Utah principally affected by the false tinder fungus, *Fomes igniarius* (L.) Gill. Schmitz and Jackson (*28, p. 24*) found no relation between crown class and the percentage of heart rot in aspen in Minnesota. Eklund and Wenmark (*9*) studying aspen, *P. tremula* L., in Sweden found that rapidly growing stands were least affected by decay. For balsam fir, *Abies balsamea* (L.) Mill., McCallum (*16, p. 13, 17*) found more decay in the faster growing trees than in the slower growing ones. Younitzky (*32, p. 117*), in a study of decay in Scotch pine in one Province in Russia, states that the dominant trees in the mature plantations are chiefly decayed by the ring-scale fungus. Koneff (*13*), in another locality in the same country, found exactly opposite conditions for the same fungus and presumably the same tree species, in that the volume of decayed wood was proportionately greater in the suppressed trees than in the more vigorous dominant ones. Dravert (*8*), in still a third locality in Russia, but again with the same wood-destroying fungus and tree species involved, found that trees in the II and III classes of suppression, according to Kraft's classification (*7, p. 447*), were relatively more heavily infected than those in the I, IV, and V classes. Münch (*21, p. 405*) determined that suppressed trees of red beech artificially infected were more susceptible to decay than thrifty, dominant ones, and explains the difference by the theory that the wood of suppressed trees has more air and hence more oxygen than the wood of dominant trees.

From all this it is apparent that the evidence on the relation of the rate of growth to degree of decay is decidedly contradictory, except that for three very different tree species decay has been found beginning earlier in the slow-growing trees than in the fast-growing ones.

The present study, with by far the largest number of trees that has ever been obtained as a basis for any exact study of decay, seemed to afford an excellent chance to investigate this point still further. Considering that vigor would be best expressed by the relation of age to volume growth, average-volume curves, which it is not necessary to present here, of volume in cubic feet over age were constructed for all the trees on each site. The trees were grouped into 50-year age classes, and the age and volume of the average tree determined for each age class to establish the points for the average-volume curve for each site. Then, according to this curve, the trees were grouped into two broad classes—those growing more rapidly than average and those growing less rapidly; and for lack of more suitable terms the words dominant and suppressed have been applied to these classes in the following tables and figures. The dominant and suppressed trees in each site were then grouped by 50-year age classes, and the age, volume in cubic feet, and percentage of decay were worked out for the average tree. These data are presented in Table 16. The comparison of dominant and suppressed trees is based on cubic-foot volume only, because board-foot volume is not an exact measure of the actual amount of wood in a tree and is far less an exact measure of the amount destroyed by decay, but is merely an approximate measure for commercial use. For the purpose of this comparison only the more exact measure would serve. For all

three sites the percentage of decay in the dominant trees is greater than in the suppressed, although on Site I there is very little difference. Of course, general averages of this kind are likely to be misleading unless the age factor is considered. For example, on Site I there is slightly more decay in the dominant trees than in the suppressed, but the former are also older, which may be the explanation. This same condition exists on Site III. However, on Site II the dominant trees which have the youngest average age have more decay than the suppressed.

TABLE 16.—*Gross volume in cubic feet and percentage of rot per average tree for dominant and suppressed Douglas firs on Sites I, II, and III grouped in 50-year age classes*

SITE I

Age class (years)	Dominant				Suppressed			
	Average age	Average volume	Rot	Trees (basis)	Average age	Average volume	Rot	Trees (basis)
1	2	3	4	5	6	7	8	9
	Years	*Cubic feet*	*Per cent*	*Number*	*Years*	*Cubic feet*	*Per cent*	*Number*
156 to 205	200	634	0	27	198	265	0.2	64
206 to 255	227	892	2.9	69	219	426	1.9	119
256 to 305	293	1,713	1.1	16	269	640	4.4	11
306 to 355	344	2,263	11.9	19	340	939	11.8	48
356 to 405	372	2,737	14.1	15	384	1,195	18.3	12
406 to 455	419	2,692	16.0	18	419	1,539	14.7	21
Total or average	277	1,415	8.8	164	260	605	8.4	275

SITE II

56 to 105	72	136	0.3	194	87	96	0.7	84
106 to 155	124	454	.9	89	125	213	1.0	124
156 to 205	177	741	3.8	91	184	338	3.1	93
206 to 255	234	896	7.3	149	236	366	4.1	215
256 to 305	278	1,066	13.2	84	280	439	9.3	86
306 to 355	331	1,339	18.8	111	332	621	12.3	150
356 to 405	372	1,637	13.4	45	373	925	7.9	52
406 to 455	428	1,923	14.5	23	428	1,030	18.4	19
456 to 505	478	2,294	18.9	2				
556 to 605	604	2,784		2	600	2,200	0	1
606 to 655	609	3,353	8.9	3	618	2,492	6.3	4
656 to 705					705	2,138	.5	1
Total or average	210	812	10.6	793	236	431	7.8	829

SITE III

56 to 105	78	164	0.9	50	80	82	0.8	46
106 to 155	130	304	2.1	68	128	127	2.2	190
156 to 205	173	378	10.5	11	172	176	1.0	18
206 to 255	220	537	7.0	13	213	184	.7	3
256 to 305					301	142	0	1
306 to 355	339	732	10.0	8	335	179	2.8	12
356 to 405	381	543	6.4	17	381	271	3.7	21
406 to 455	417	570	4.5	31	418	294	5.8	24
456 to 505	487	622	.8	3	467	436	0	1
506 to 555	511	1,394	16.7	2	522	448	19.7	2
556 to 605					567	635	0	1
606 to 655	612	829	1.0	1				
Total or average	211	382	5.0	204	182	152	3.0	319

Accordingly, to illustrate more exactly the difference between the two classes of trees, the data in the tables are shown in Figure 12. On Site I, it appears that the suppressed trees have slightly more decay than the dominants throughout, although there were no trees

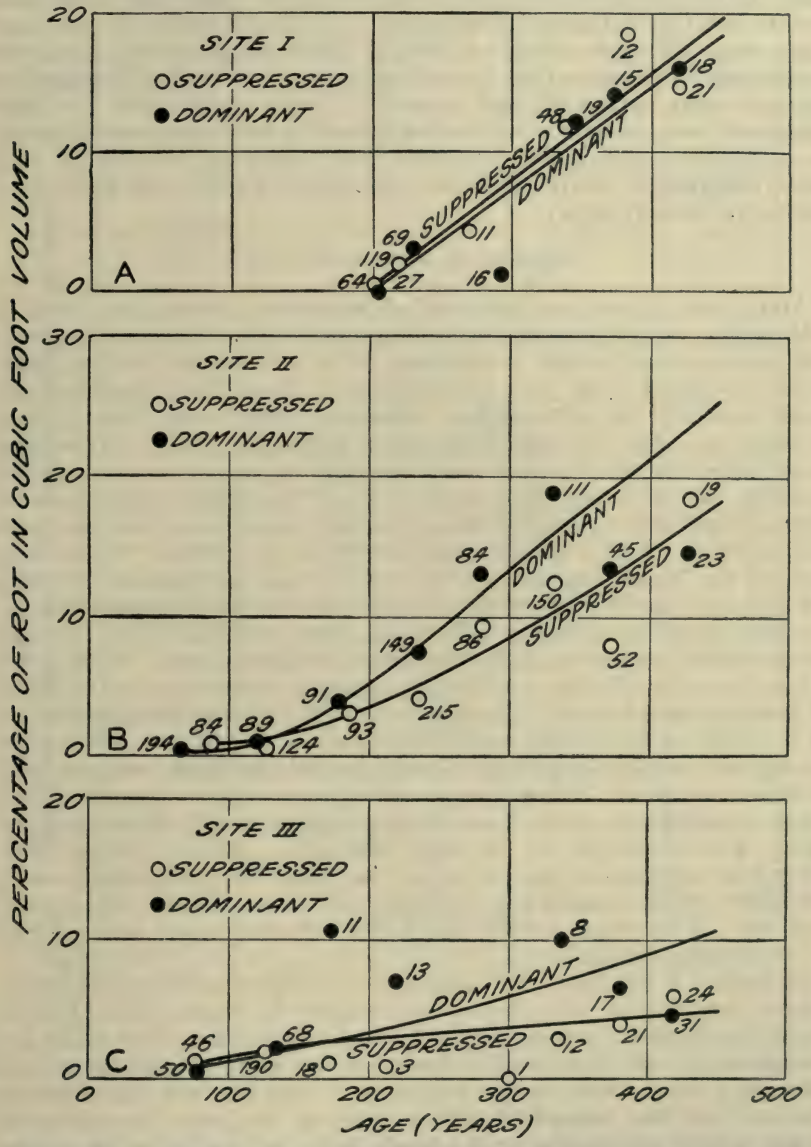


FIGURE 12.—Percentage of rot in gross volume in cubic feet per average tree in relation to age for dominant and suppressed Douglas firs: A, Site I; B, Site II; C, Site III

in the younger ages on this site. But on Sites II and III, the suppressed trees are slightly more subject to rot in their earlier years than the dominants and less as they grow older, the curves crossing at approximately 125 years for Site II and 165 years for Site III. In

the older age classes there is much less rot in the suppressed trees than in the dominants. If there is justification for formulating any ideas at all from this somewhat contradictory evidence it might be considered that on Sites II and III suppression tended to increase decay in the younger ages, but as the trees grew older and more subject to rot this influence disappeared. Unfortunately, the younger ages were not represented on Site I. This tendency for decay of consequence to begin at an earlier age accords with the findings for incense cedar, white fir, and aspen in Utah. As to why the older dominant trees were more decayed than the older suppressed trees, no reasonable explanation suggests itself, although it may be that after Douglas fir attains a certain age, which varies with site, vigor has no relation to decay.

RELATION OF ROT TO LOCALITY

Many ideas have been advanced in regard to the relation between soil quality, depth, and moisture, degree of slope, exposure, altitude, and general locality and the amount of rot in Douglas fir, but these ideas are found to be very contradictory. Some hold that decay is more prevalent on north slopes, others on south; some claim that it is worse on ridge tops, others in valley bottoms; or steep slopes may be opposed to gentle, deep soil to shallow, moist soil to dry, or gravelly soil to loam. But most of these ideas have been based on limited observation, usually over relatively small areas, and never on a detailed study over the Douglas fir region as a whole. Consideration of the factors mentioned showed no tangible relation between rot and any one of them on the 38 plots in this study, except that, as brought out previously, the indications were that Site I had the least decay, and it is this site, of course, that has the best soil. A study of a great number of plots would be necessary to determine the influence of these various factors. Havelik (*11*, *p. 354*), from his observations of red ring rot in Norway spruce, *Picea abies* (L.) Karst. (*P. excelsa* Link), in middle Europe and Sweden, concluded that trees on poor soils and unusually rich soils were much more subject to attack than those on optimum soils, because low-quality wood which decayed easily was developed on the first two soils. Möller (*20*, *p. 201*), after his extensive investigation of red ring rot in Scotch pine in Germany, decided there was no relation between quality of the wood and rot. With equal facility the decay attacked wood with narrow or wide annual rings.

However, it has been the consensus of opinion among those thoroughly acquainted with the entire Douglas fir region that Douglas fir in the northern section of the Cascade Mountains, beginning approximately with the Cowlitz River watershed in Washington and extending north, was on the whole much less decayed than that to the south of this watershed, particularly in Oregon, although occasional individual stands to the north were just as defective as any to the south. It seemed the explanation might be the fact that the timber to the south was on the average older than the stands to the north or that in general it occupied poorer sites.

Accordingly, a comparison was made between the northern and southern Site II plots in Table 17. This could not be done for Site I or Site III, since of the five plots in the former four were in the

north, and of the seven plots in the latter six were in the south. From Table 17 it can be seen by following columns 4 and 5, which give the percentage classes, that the loss from decay is generally much higher in the southern plots than in the northern; in fact, the average of all southern plots is 19.5 per cent and for the northern, only 7.3 per cent. To be sure, the 14 plots in the south average 51 years older than the 12 plots in the north, but this does not serve to explain the difference as brought out by Figure 13, in which the data in Table 17 are shown. These curves show that except in the youngest age classes the percentage of decay is much higher through-

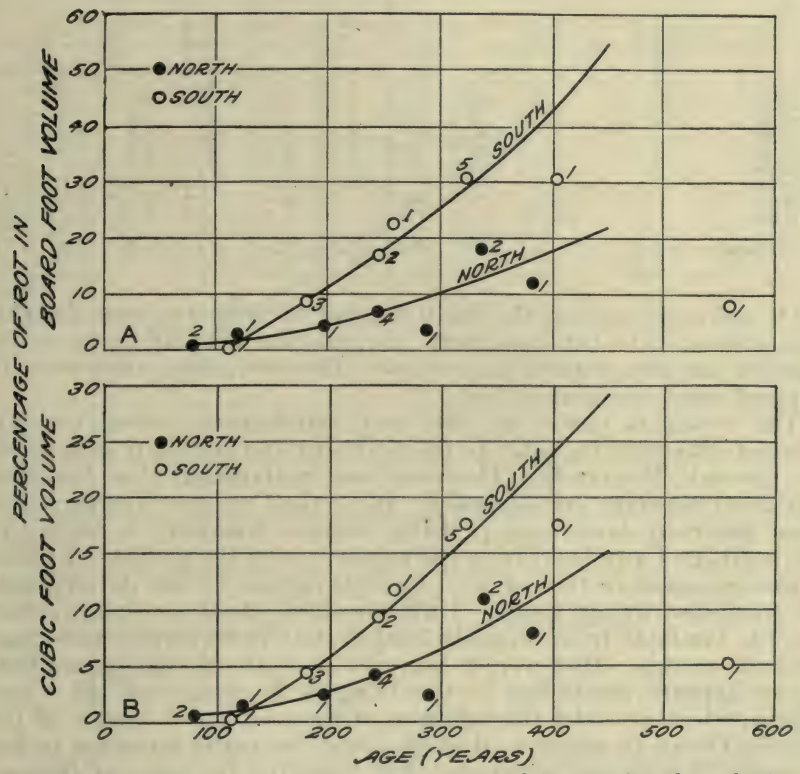


FIGURE 13.—Percentage of rot in relation to age of Douglas firs of merchantable size on Site II in the northern and southern sections of the region, based on gross volume per acre: A, Board feet (Scribner Decimal C rule); B, cubic feet

out in the southern plots than in the northern. The fact that this relation does not hold in the younger classes may be owing to experimental error, since there are three northern plots between 51 and 150 years and only one southern. The difference can not be explained by a variation in site between the two groups, even though they fall in the same site; that is, the northern group being good, Site II and the southern group poor, since the average site index is 176 for the northern plots and 173 for the southern. Furthermore, the difference can not be owing to relative chances of infection, for decay is so prevalent throughout the Douglas fir region that there is abundant opportunity for every stand to be infected.

TABLE 17.—*Comparison of percentage of rot for the northern and southern sections of the region in Douglas firs of merchantable size by plots on Site II grouped in 50-year age classes, based on gross board-foot and cubic-foot volumes per acre*

Age class (years)	Average age		Rot in—				Plots (basis)	
			Board-foot volume		Cubic-foot volume			
	North	South	North	South	North	South	North	South
1	2	3	4	5	6	7	8	9
	Years	*Years*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Number*	*Number*
50 to 100	79	-------	0.5	-------	0.3	-------	2	-------
101 to 150	122	112	2.9	0.2	1.3	0.1	1	1
151 to 200	197	180	4.2	8.5	2.4	4.3	1	3
201 to 250	241	245	6.9	16.7	4.1	9.3	4	2
251 to 300	289	258	3.5	22.5	2.2	11.6	1	1
301 to 350	339	323	18.1	30.6	10.8	17.6	2	5
351 to 400	383	-------	12.0	-------	7.7	-------	1	-------
401 to 450	-------	404	-------	30.9	-------	17.5	-------	1
551 to 600	-------	559	-------	8.2	-------	5.1	-------	1
Average or total	233	284	7.3	19.5	4.4	11.0	12	14

Of course, because of the small number of plots available for this comparison it is not positively proved that the difference exists between the two regions as a whole. However, these data tend to support previous observations.

The writer is unable to offer any satisfactory reason for this marked difference in decay in the northern and southern sections of the Cascade Mountains. However, one explanation that has been advanced deserves consideration: It is that summer temperatures seem generally lower and probably relative humidity is higher in the northern Cascades than in the southern, and the probable warmer growing season in the south is more favorable to the development of wood-destroying fungi. Unfortunately, there are no weather records available from properly located stations to permit more than surmise on this. However, it may not be without significance that decay appears much less in the Douglas fir stands of the Coast Range, which is under the influence of the cool, moist breeze off the Pacific Ocean in summer, than in stands at equal latitudes in the Cascade Mountains farther removed from the influence of the sea.

TOTAL LOSS

Although each individual loss caused by one of the various factors which have been discussed has its own degree of importance, the true picture of the total loss in Douglas fir timber which has been felled can be obtained only by considering these losses in the aggregate. Table 3 shows that 15 of the 38 plots suffered total losses of 25 per cent or more, measured in board feet, and that few plots more than 100 years old escaped with losses of less than 10 per cent. The largest total loss, 61.5 per cent, occurred on plot 38. Adding to this figure the additional loss through damage in logging and through hidden defects revealed only by sawing, it is apparent that an extremely small amount of finished lumber will be obtained from

such a defective stand. There is the further indirect loss in the increased cost of logging, for it costs just as much to construct a logging railroad and set up equipment on an area with a total output of only 75,000 board feet per acre, net, as on an area with an output of 150,000 board feet. Neff (*25, p. 593*) considers that in the northern Rocky Mountain region defect increases the cost of production in nearly the same ratio as the occurrence of the defect itself. The number of cull logs left from a stand with a high total loss is shown in Plate 10, A. The photograph was taken on the general area on which plot 38 was located.

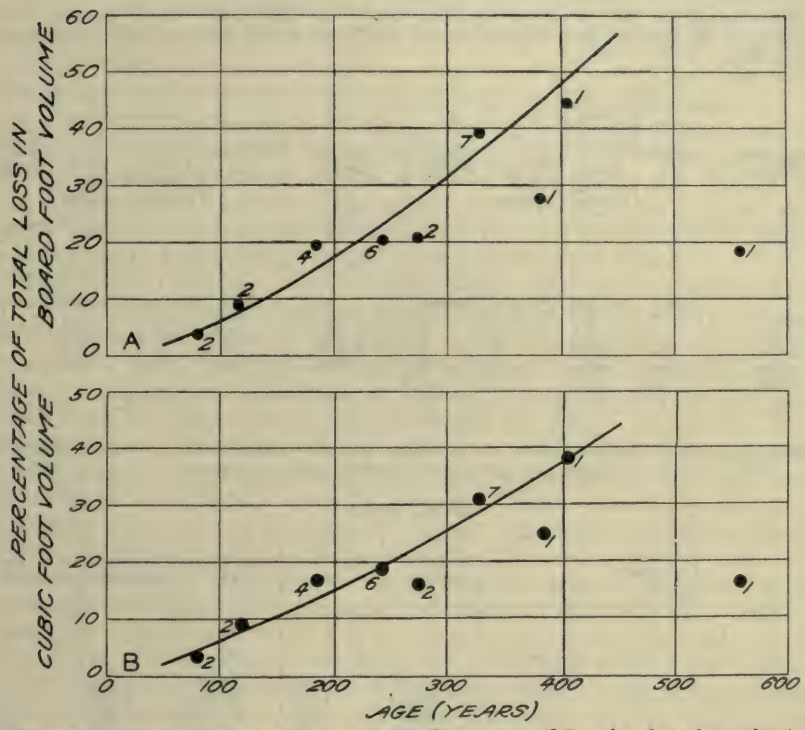


FIGURE 14.—Percentage of total loss in relation to age of Douglas firs of merchantable size on Site II based on gross volume: A, Board feet (Scribner Decimal C rule); B, cubic feet

The general tendency for loss to increase as the stand grows older reveals itself in Table 4. This is to be expected, since rot causes such a large part of the entire loss, while breakage in felling increases with the volume per acre of the stand, and this volume, up to a certain limit, also increases with the age of the stand. In Table 18, the percentage of total loss, measured in board feet and in cubic feet, is given for Site II plots grouped in 50-year age classes. From these percentages, curves showing the relation of total loss to age were constructed for Figure 14. From these curves and those for volume per acre (fig. 3), Table 19 was constructed in the manner described on page 37 to show the relation of increment in gross volume to the increment in total-loss volume. This table shows that on Site II

the total-loss increment does not equal gross increment in board-foot volume until 270 years at the earliest, and this age is well beyond any probable future rotation for Douglas fir. Of course, for some time previous to the age at which total-loss increment equals gross increment in a stand, the net increment of sound wood will not be sufficient to offset carrying charges, so that actual financial loss will begin earlier than the loss in volume.

These figures on total loss, since they include the percentage of breakage without regard to the topography, show only the trend of total loss and should not be applied directly to other stands.

TABLE 18.—*Total loss in Douglas firs of merchantable size by plots on Site II grouped in 50-year age classes, based on gross board and cubic foot volumes per acre*

Age class (years)	Average age	Total loss in—		Plots (basis)	Age class (years)	Average age	Total loss in—		Plots (basis)
		Board-foot volume	Cubic-foot volume				Board-foot volume	Cubic-foot volume	
1	2	3	4	5	1	2	3	4	5
	Years	*Per cent*	*Per cent*	*Number*		*Years*	*Per cent*	*Per cent*	*Number*
51 to 100	79	3.6	3.3	2	301 to 350	328	39.1	31.7	7
101 to 150	117	8.8	9.8	2	351 to 400	383	27.5	25.3	1
151 to 200	184	19.2	17.0	4	401 to 450	404	44.5	38.3	1
201 to 250	242	20.4	18.9	6	551 to 600	559	18.1	17.1	1
251 to 300	273	20.5	16.2	2					

TABLE 19.—*Periodic increment in average gross volume and average total loss volume per acre for Douglas fir on Site II*

BOARD FEET [1]

Age (years)	Gross volume	Total loss volume	Gross increment	Total loss increment	Percentage of total loss
1	2	3	4	5	6
50	20,000	300	20,000	300	1.5
100	69,000	3,930	49,000	3,630	5.7
150	110,000	11,100	41,000	7,170	11.0
200	136,000	23,260	26,000	12,160	17.1
250	158,000	37,760	22,000	14,500	23.9
300	174,000	54,640	16,000	16,880	31.4
350	186,000	72,910	12,000	18,270	39.2
400	196,000	93,490	10,000	20,580	47.7
450	203,000	114,700	7,000	21,210	56.5

CUBIC FEET [2]

50	3,900	78	3,900	78	2.0
100	12,200	744	8,300	666	6.1
150	17,500	1,820	5,300	1,076	10.4
200	21,100	3,228	3,600	1,408	15.3
250	23,850	4,913	2,750	1,685	20.6
300	26,000	6,812	2,150	1,899	26.2
350	27,700	8,892	1,700	2,080	32.1
400	28,900	11,040	1,200	2,148	38.2
450	29,600	13,231	700	2,191	44.7

[1] Total loss increment equals gross increment at approximately 270 years.
[2] Total loss increment equals gross increment at approximately 295 years.

APPLICATION OF RESULTS

A knowledge of the indications of decay in logs and standing trees is an absolute prerequisite to relatively exact scaling and cruising. The importance of accurate scaling and cruising is evident, since the entire lumber industry is largely dependent on them. Logs are bought and sold on board-foot scale alone, timberland changes hands, and logging operations are based on the amount of timber that can be obtained from a given unit of area as determined by cruising. Consequently, exact cruising and scaling reduce the financial risk in the lumber industry, particularly in exploiting a species such as Douglas fir with a large amount of defect. When logs are purchased which actually cut out considerably less than scaled, there is a serious loss; but even more serious is the loss when a mill and railroad are constructed and logging equipment set up only to find that because of decay the amount of timber obtained from the area tributary to the mill is so much less than estimated that it is not possible to make a profit throughout the life of the operation. The financial difficulties of more than one lumber company cutting overmature Douglas fir can be attributed to underestimating the amount of decay when cruising the stand.

The indications by which the presence and approximate extent of the various decays may be determined have been given on pages 23 to 30 and in previous papers (*3*, *4*, *5*). In addition, the average losses that can be expected from other causes, such as shake, miscellaneous defect, and breakage in felling, on which heretofore there have been no exact data, are discussed on pages 11 to 22. It is essential to understand the significance of various other abnormalities such as burls, branch fans, and dead limbs, which are often mistakenly considered signs of decay. These have been discussed in detail (*4*, *p. 11*) in a previous paper. With this information the scaler or cruiser can work in Douglas fir with relative accuracy. The scaler has a simpler problem than the cruiser, because he can examine the logs at close range and observe not only the conks or swollen knots on the sides but also the presence in the ends of the logs of rot indicated by decomposed or discolored wood. The cruiser, on the other hand, must examine standing trees, which is not an easy task, since mature Douglas firs 250 feet high are not uncommon. In fact, field glasses or binoculars are necessary in order to pick out the conks and swollen knots in the upper part of the trunk with any accuracy. The cruiser should use a volume table based on diameter breast high and number of 32-foot logs, but giving the volume in each log. Only in this way is it possible to evaluate properly the loss through decay, since quite commonly, in Douglas fir, decay does not extend throughout the length of the trunk, but includes only one or more logs or parts of logs.

The information on the amount of defect other than decay in Douglas fir is not so difficult to apply. For example, a stand of timber approximately 300 years old, as determined from several windfalls or adjacent cutting operations, has been cruised and found to average 150,000 board feet per acre gross, with an estimated loss from decay of 15 per cent. In a stand of 150,000 board feet per acre on smooth ground a loss of 8 per cent from breakage in felling

may be expected (fig. 5) and the loss through shake in a 300-year-old stand averages 1.1 per cent. (Fig. 4.) Miscellaneous defect averages 0.6 per cent, as stated on page 14. Combining these makes a total loss of 24.7 per cent, with a resulting stand of 112,950 board feet per acre.

Still another use can be made of the indications of decay, and that is identification of trees which, because of decay, contain no merchantable volume or so little they are not worth felling. Felling and bucking charges can be avoided by leaving such trees standing. The trees which are felled should be carefully marked for bucking so as to get the maximum of merchantable wood and exclude the unmerchantable. Cull sections of the trees should be designated to be left in the woods. The aim should be to spend as little money as possible on unmerchantable timber, for it must be remembered that it costs just as much to fell, buck, transport, and mill an unmerchantable log as a sound one. In fact, on an operation in defective timber it should be the work of one trained man to select defective trees to be left standing and mark felled trees for bucking to exclude unmerchantable logs. There can be no question that this would be profitable, because the values involved in the proper utilization of a badly defective stand are high.

This work must not be left to untrained judgment; it must be done skillfully, otherwise heavy losses will result. Plate 11 shows trees left uncut on a logging operation because they were considered unmerchantable, owing largely to red ring rot. Later a railroad right of way was cut through this timber, and many of these trees were found to be partially or completely merchantable. Some years ago an operator logged a half section, leaving a large number of trees standing as decayed in the judgment of the fellers. Shortly after there was a change in woods management, and it was decided to log the remaining trees on the same area. The log scale obtained from the supposedly decayed trees was only approximately 4 per cent less than that from the presumably sound ones first cut.

Leaving decayed trees standing not only reduces logging costs, but these trees will serve as seed trees to aid in restocking the cut-over area. It has been pointed out by the writer in a previous paper (*6*) that the usual objections that such trees will spread decay to the future stand and will produce poorer seed resulting in poorer seedlings are not important, because the future even-aged stands of second-growth Douglas fir managed on a clear-cutting system will be cut before the trees attain the age at which they become subject to extensive decay, and because there seems to be no sound biological reason for decay, which attacks the dead heartwood only, to so affect the vital functions of the tree that the quality of the seed is reduced. Furthermore, much of the reproduction on cut-over land must come from seed dropped by the trees just previous to logging or by seeding in from the adjacent stand, so that if the original stand contains decayed trees, seedlings from this seed source can not be prevented from forming a proportionate part of the future stand. Then, too, cones on sound seed trees will be cross-fertilized to some extent by pollen from decayed trees in the immediate or in the adjacent stand. Furthermore, experience has shown that of the seed trees left, some will be killed by the subsequent slash burning and others will

die from the shock of sudden exposure and change in site conditions incident to clear cutting, so that investment in sound seed trees would be a relatively heavy one. Of course, many operators are not interested in restocking their land, but all are certainly interested in reducing costs; and it should be remembered that most companies must hold their cut-over land for some time in order to give adequate fire protection to their equipment, so that it is certainly desirable to have this land become an increasingly valuable asset by restocking with young trees rather than remain continuously nonproductive or less productive, particularly when the restocking can be accomplished at no additional expense.

At present clear cutting is practically universal in the Douglas fir region. On the national forests scattered seed trees are left as an insurance for future reproduction, and on some private operations completely defective trees are left. Where small trees—that is, 16 inches in diameter breast high or less—occur among larger trees they are usually left standing, but are mostly so badly broken up by felling and logging the larger ones that they are of little or no value to the succeeding stand. Those that do escape logging injury are usually damaged or killed by slash burning. The best method for reproducing the future stands when the forests of the region are brought under regulation has not yet been determined. It may be that in regulated stands repeated clear cutting with scattered seed trees on a relatively short rotation, even if not followed by broadcast slash burning, may be so deleterious to the soil that some other method will have to be used. Whether the shelter-wood method, or a modification of it, will replace the present method is problematical. If the shelter-wood method is sometimes practiced, it will be possible to remove by the first cutting the occasional infected trees that will appear in the second-growth stands. But it seems certain, as stated by Munger (*24*, *p. 35*), that clear cutting will be the practice for 20 to 30 years more.

Any attempt to remove the decayed trees from the present mature and overmature stands in advance of final logging seems ill-advised unless the material removed will pay the cost of the operation. Their removal is not necessary as a protection to the future stands, and its effectiveness in lessening the increase in decay through reducing new infections in present stands would be very problematical unless the work were carried on over extensive areas, comprising natural topographical units such as entire watersheds.

In many tree species subject to decay there is a very definite relation between the amount of decay and the character and degree of wounding, particularly scars caused by fire, so that a reduction in mechanical injuries will be followed by a reduction in loss from rot. Consequently, adequate fire protection is, in addition to its primary usefulness, an effective control measure against decay. In Douglas fir, red-brown butt rot is commonly associated with fire scars, so that some control can be accomplished by lessening fires. However, red ring rot, which causes 80 per cent of the loss, rarely enters the tree through open wounds, but almost invariably infects through dead-branch stubs; consequently in Douglas fir less reduction in decay losses can be accomplished by protecting stands from mechanical injuries than in other species on which exact informa-

tion has been gathered. It may be that in the managed forests of the future, when understocking is not so common, the loss from red ring rot will be somewhat lessened, since the development of branches should decrease with increase in density of the stand, giving fewer points of entrance for this rot.

According to McArdle (*15, p. 41*), the greatest average yearly production of wood volume measured in board feet (Scribner Decimal C rule) on Sites I, II, and III is reached before the stand attains the age of 110 years; therefore, it is unlikely that in the managed forests of the future the cutting age will extend much beyond this time. For the national forests, a rotation of 110 years is planned. According to Figure 9, the average loss from decay at this age on Site II is 1.4 per cent, and the worst loss to be expected on Site II is 2.8 per cent. These figures show that in the managed and naturally reproduced stands of the future the loss from decay on Site II will be small by the time cutting age is reached. The same relation will probably hold for Sites I and III.

Although the loss from decay in young timber is of minor importance, there are now and will be for some time in the future mature and overmature stands in which the rate of decay or total loss is important, since it will determine whether the stand can be held or must be utilized promptly. Table 12 shows that on Site II under average conditions, loss through decay measured in board-foot volume equals increment at 300 years, and from then on exceeds it; and Table 19 shows that for total loss the same thing occurs at 270 years. Even before loss equals increment, however, there may be a financial loss, because the net growth of sound wood will not offset the carrying charges, such as taxes, interest on the investment, protection costs, and overhead. On the other hand, the appreciation in the value of stumpage and the development of methods of closer utilization may offset this financial loss and even the net loss in volume for some years after such volume loss begins. Then, too, if rot is largely confined to the center heartwood, the grade of lumber sawed may actually be higher than the average, since the low-grade, knotty lumber comes largely from the center of the tree. When decayed, this portion changes from low grade to unmerchantable. But, finally, there will come a time when financial loss can not be further postponed; if this time does not come sooner, it will certainly begin when the stand starts to break up with the continual dropping out of large trees of high value. Even then cutting may have to be postponed for a time to avoid the even greater loss of selling lumber on a low market.

From the foregoing it is evident that no definite rule can be given by which to determine exactly when Douglas fir timber should be cut, since, besides the rate of decay and other losses, so many factors are present that each stand demands separate consideration. The first essential for each working circle is a complete stock taking, including for the stands composing it the average age, volume per acre and percentage of rot as determined by cruising, site, and topography. With these data it will be possible to determine one point relating percentage of decay to age, and to draw a curve similar in form to one of those in Figure 9. By such a curve the rate of decay for the future can be approximately predicted. To this

can be added the loss through shake, predicted on the basis of the age of the stand; the average loss from miscellaneous defect and the probable loss from breakage, calculated with reference to the density of the stand and the character of the ground. These data can then be applied to gross-yield figures as determined from yield tables, and the net yield can be predicted, together with the time at which loss equals growth and net loss succeeds net yield for an extended period. It must be remembered that this method of predicting loss is an approximation and that absolute exactness can never be obtained by further refinement—that is, by using more plots as a basis for the curves—or by any other method; and that up to now no method of estimating future loss in stands has existed, other than that of individual judgment, which is very uncertain at best.

In the application of yield tables, a knowledge of prospective loss is essential. Yield tables are based on normal—that is, fully stocked—stands and gross yield. But the net yield and not the gross yield is important, since the former determines the monetary return when the stand is cut; so that a yield study in any timber type subject to defect is not complete unless accompanied by a study of loss.

For example, McArdle (*15*, *Table 4*) shows that on Site II with a site index of 170 the gross yield in a normal stand of Douglas fir 150 years old will be 121,200 board feet per acre by the Scribner Decimal C rule. Figure 9 shows that the average loss from decay on Site II at this age is 4 per cent. From Figure 4 it is seen that the loss from shake is 0.5 per cent (reading to the nearest tenth), and that the usual loss from miscellaneous defect is 0.6 per cent (page 14). For a stand of 121,200 board feet per acre the average breakage in felling on smooth ground is 7.2 per cent and on rough ground 10.8 per cent. (Fig. 5.) The total of all these loss factors will be 12.3 per cent or 15.9 per cent, according to whether the ground is smooth or rough. The gross stand of 121,200 board feet per acre must therefore be reduced by 12.3 or 15.9 per cent, depending on the character of the ground. In addition the net yield will be still further reduced by understocking. From Figure 3 it can be seen that at 150 years the average gross yield of the plots studied was 110,000 board feet, or 9.2 per cent less than the yield of a fully stocked stand as determined by McArdle. For years to come, varying degrees of understocking will be the rule rather than the exception in the naturally stocked second-growth stands throughout the Douglas fir region. Meyer (*19*, *p. 641*) has found that the average stand of immature Douglas fir has from 82 to 83 per cent of the normal board-foot volume. Fully stocked stands will occur over restricted areas only.

SUMMARY

Douglas fir is the most important timber tree of the Pacific Northwest and comprises about one-fourth of the remaining saw timber in the United States. Since the species is necessary to the economic future of the region in which it attains optimum development—western Oregon and Washington west of the summit of the Cascade Mountains and north of the Umpqua-Rogue River divide—a series of investigations of which this is one has been made on the life

history and habits of the tree, to provide a sound basis for its management.

In the region in question Douglas fir is very little affected by insects, fungi (except heartwood destroyers), or mistletoe. The Douglas fir bark beetle, *Dendroctonus pseudotsugae* Hopk., is abundant in felled trees, but has caused no great losses in living timber. A woolly aphid, *Chermes cooleyi* Gill., is common but relatively harmless. Periodically the western hemlock looper, *Ellopia fervidaria* Hbn., destroys considerable merchantable timber in some localities. The needle-cast fungus, *Rhabdocline pseudotsugae* Syd., causes considerable defoliation on young trees over limited areas. The relatively harmless needle-rust fungus, *Melampsora albertensis*, Arth., has not been found in the region. Seedlings and saplings are occasionally killed by the honey fungus, *Armillaria mellea* (Vahl) Fr. The conifer root fungus, *Fomes annosus* (Fr.) Cke., has not been found as a parasite. Douglas fir dwarf mistletoe, *Razoumofskya douglasii* (Engelm.) Kuntze, is unknown. A form of winter injury known as parch blight reddens the needles on trees in the winter, but the affected trees are rarely injured severely. Young stands are sometimes seriously damaged by ice storms, known locally as "silver thaws," or by wet-snow storms. However, the losses caused by the foregoing are small compared with the enormous losses through decay caused by wood-destroying fungi.

A detailed study of loss in Douglas fir was made on 38 plots covering 77.79 acres and containing 2,633 trees with a total volume of over 10,146,000 board feet or 1,571,000 cubic feet. The loss caused by rot amounted to 16.99 per cent in board-foot volume and 9.50 per cent in cubic-foot volume; 9.25 per cent of the volume in board feet and 12.57 per cent of the volume in cubic feet was broken in felling; shake accounted for a loss of 0.93 per cent in board-foot volume and 0.55 per cent in cubic-foot volume; and miscellaneous defects, such as broken top, volunteer, crook, fork, knots, insects, fire scar, and check, were responsible for a reduction of 0.60 per cent in the board-foot volume and 0.73 per cent in the cubic-foot volume, making a total loss of 27.77 per cent in board-foot volume and 23.35 per cent in cubic-foot volume.

The loss through shake increased with the age of the stand. There was no relation between miscellaneous defect and the age of the stand. Breakage in felling was influenced by topography, density of the stand, and size of the trees—the greater losses occurring on the rougher ground, in the denser stands, and among the larger trees.

Of the loss by decay, red ring rot caused by the ring scale fungus, *Trametes pini* (Thore) Fr., was responsible for 80.8 per cent in board-foot volume; brown trunk rot caused by the quinine fungus, *Fomes laricis* (Jacq.) Murr., for 8.6 per cent; red-brown butt rot caused by the velvet-top fungus, *Polyporus schweinitzii* Fr., for 6.2 per cent; yellow-brown top rot caused by the rose-colored conk, *F. roseus* (Alb. and Schw.) Cke., for 4.1 per cent; pitted sap rot caused by the purple fungus, *Polystictus abietinus* (Dicks.) Fr., for 0.1 per cent; spongy sap rot caused by the conifer root fungus, *F. annosus* (Fr.) Cke., for 0.1 per cent; and unknown rots for 0.1 per cent. In cubic-foot volume measurements these figures were:

Red ring rot 79.2 per cent, brown trunk rot 8.4 per cent, red-brown butt rot 7.9 per cent, yellow-brown top rot 4.0 per cent, pitted sap rot 0.2 per cent, spongy sap rot 0.1 per cent, brown cubical rot caused by the sulphur fungus, *Polyporus sulphureus* (Bull.) Fr., trace, and unknown rots 0.1 per cent. There are definite indications on the trunks of living trees of the presence of the more important of these rots in the heartwood; red ring rot in particular being easily detected by swollen knots and conks, and red-brown butt rot by fire scars, churn butts, and conks. The greatest loss in any one plot amounted to 54.8 per cent in board-foot volume and 32.2 per cent in cubic-foot volume, nearly all of which was caused by red ring rot.

Scars are of minor importance as a means of entrance for decay, because red ring rot almost invariably enters through dead-branch stubs or knots. Of the scars, those caused by fire are of most importance, because red-brown butt rot commonly enters through fire scars, and this decay not only attacks the heartwood of the valuable butt log but also predisposes trees to windfall.

Actual loss through decay may appear in individual trees rather early in the life of a stand. Red ring rot was found causing loss in a tree 27 years old, red-brown butt rot in one 73 years old, yellow-brown top rot in one 76 years old, and brown trunk rot in one 146 years old. It was apparent that this latter decay appeared later in the life of a stand than the other three.

Although occasional stands remained relatively free from decay throughout their life, as a rule the amount of decay increased rapidly in mature and overmature stands. The data were not sufficiently comprehensive to determine definitely if there was any relation between site and decay, but they seemed to indicate that in the younger ages rot is of least consequence on Site I and is more serious on Site III than on Site II. There were only five plots on Site I, seven on Site III, and none on Sites IV and V. On Site II, in board-foot volume, rot increment equaled gross increment at 300 years, and in cubic-foot volume at 345 years. In other words, from those periods on, the stands were not making a net growth but were actually losing in volume. The most rapid rate of increase in decay in the most highly defective stands was 23.1 per cent of the gross board-foot volume for a 50-year period from 300 to 350 years, or an average of 0.46 per cent a year. For the average stands on Site II, the most rapid increase in decay averaged 0.29 per cent a year from 400 to 450 years.

Although no definite relation was found between vigor of the trees and decay, there were indications that on Sites II and III suppression tended to increase decay in the younger trees up to 125 and 165 years, respectively, but beyond these ages this influence disappeared, and the dominant ones had most decay. Trees in the younger age classes were not represented on Site I.

In the northern portion of the region covered by this study the loss through decay was less than that in the southern portion for stands of the same age and site index, although the number of plots studied was not sufficient to settle the point conclusively. The data support general observations made previously.

Total loss, which included decay, shake, miscellaneous defect, and breakage in felling, but not waste, also increased with the increasing age of stands. On Site II in board-foot volume, total-loss increment

equaled gross increment at 270 years. The same period in cubic-foot volume was reached at 295 years.

Ability to recognize and interpret indications of decay in standing trees and logs, together with the information on the average losses that may be expected from other causes, will make possible more exact cruising and scaling. Trees which because of decay contain no merchantable volume, or so little that they are not worth felling, can be identified in advance of logging and left standing, so that felling charges are saved; further, such trees will serve as seed trees. After the stand is felled the partially decayed trees can be carefully marked for bucking in order to get the maximum of merchantable volume and leave the unmerchantable material on the ground, thus saving logging and milling costs.

In the future Douglas fir stands will ordinarily be cut before they attain the age of 110 years, and at this age the loss through decay is small on Sites I, II, and III. However, large areas are still occupied by mature and overmature stands, and figures on the rate of decay and other losses can be applied to these stands to determine whether they can be held or should be utilized as promptly as possible. Furthermore, yield tables which deal only with gross volume are incomplete without loss tables, which make it possible to predict net volume. This study has partially supplied such loss tables to supplement the yield tables previously completed.

LITERATURE CITED

(1) ANONYMOUS.
1926. SAWING THE TOUGH BUTT LOGS. West Coast Lumberman 50 (596): 67. (Signed "A Southern Oregon Filer.")

(2) BOYCE, J. S.
1920. THE DRY-ROT OF INCENSE CEDAR. U. S. Dept. Agr. Bul. 871, 58 p., illus.

(3) ———
1921. DECAY IN DOUGLAS FIR. Timberman 23 (1): 129, 133, illus.

(4) ———
1923. A STUDY OF DECAY IN DOUGLAS FIR IN THE PACIFIC NORTHWEST. U. S. Dept. Agr. Bul. 1163, 20 p., illus.

(5) ———
1924. DECAY IN DOUGLAS FIR IN RELATION TO CRUISING. Timberman 26 (1): 51–54, illus.

(6) ———
1927. DECAY AND SEED TREES IN THE DOUGLAS FIR REGION. Jour. Forestry 25: 835–839.

(7) DENGLER, A.
1930. WALDBAU AUF ÖKOLOGISCHER GRUNDLAGE, EIN LEHR- UND HANDBUCH. 560 p., illus. Berlin.

(8) DRAVERT, V. P.
1929. [HEART ROT OF THE PINE IN THE SOKOLVASKAYA AND BOROVLIANSKYA FOREST ESTATES (TAXATION SURVEY).] [IN RUSSIAN.] Reprinted from Siberian Inst. Agr. and Forestry (Omsk) Trans. v. 12, no. 3, 13 p. [Original not seen. Abstract in Rev. Appl. Mycol. 8 (6): 415. 1929.]

(9) EKLUND, S., and WENMARK, G.
1925. NÅGRA UNDERSÖKNINGAR AV ASPSKOG. Skogsvårdsför. Tidskr. 23: 80–104, 125–142, illus.

(10) HANZLIK, E. J., and FULLER, F. S.
1917. A STUDY OF BREAKAGE, DEFECT, AND WASTE IN DOUGLAS FIR. Wash. [State] Univ. Forest Club Ann. 5: 32–39, illus.

(11) HAVELIK, K.
1924. KERNFÄULE FICHTE. Centbl. Gesam. Forstw. 50 (7–12): 348–357.

(12) HOFMANN, J. V.
1924. THE NATURAL REGENERATION OF DOUGLAS FIR IN THE PACIFIC NORTHWEST. U. S. Dept. Agr. Bul. 1200, 62 p., illus.
(13) KONEFF, G. I.
1929. [HEART ROT OF THE PINE IN THE TSCHUMYSHSKY FOREST, BARNAUL DISTRICT (TAXATION SURVEY).] [In Russian.] Reprinted from Siberian Inst. Agr. and Forestry (Omsk) Trans. [Abstract in Rev. Appl. Mycol. 8 (6): 414. 1929.]
(14) MCARDLE, R. E.
1926. NEW YIELD TABLES FOR DOUGLAS FIR. West Coast Lumberman 50 (590): 100–101, 105, illus.
(15) ——— and MEYER, W. H.
1930. THE YIELD OF DOUGLAS FIR IN THE PACIFIC NORTHWEST. U. S. Dept. Agr. Tech. Bul. 201, 64 p., illus.
(16) MCCALLUM, A. W.
1928. STUDIES IN FOREST PATHOLOGY. 1. DECAY IN BALSAM FIR (ABIES BALSAMEA, MILL.). Canada Dept. Agr. Bul. (n. s.) 104, 25 p., illus.
(17) MEINECKE, E. P.
1916. FOREST PATHOLOGY IN FOREST REGULATION. U. S. Dept. Agr. Bul. 275, 63 p.
(18) ———
1929. QUAKING ASPEN: A STUDY IN APPLIED FOREST PATHOLOGY. U. S. Dept. Agr. Tech. Bul. 155, 34 p., illus.
(19) MEYER, W. H.
1929. A STUDY OF THE RELATION BETWEEN ACTUAL AND NORMAL YIELDS OF IMMATURE DOUGLAS FIR FORESTS. Jour. Agr. Research 41: 635–665, illus.
(20) MÖLLER, A.
1929. DER WALDBAU; VORLESUNGEN FÜR HOCHSCHULSTUDENTEN . . . v. 1, 560 p., illus. Berlin.
(21) MÜNCH, E.
1910. VERSUCHE ÜBER BAUMKRANKHEITEN. Naturw. Ztschr. Forst u. Landw. 8: 389–408, 425–447, illus.
(22) MUNGER, T. T.
1911. THE GROWTH AND MANAGEMENT OF DOUGLAS FIR IN THE PACIFIC NORTHWEST. U. S. Dept. Agr., Forest Serv. Circ. 175, 27 p., illus.
(23) ———
1916. PARCH BLIGHT ON DOUGLAS FIR IN THE PACIFIC NORTHWEST. Plant World 19: 46–47.
(24) ———
1927. TIMBER GROWING AND LOGGING PRACTICE IN THE DOUGLAS FIR REGION. U. S. Dept. Agr. Bul. 1493, 42 p., illus.
(25) NEFF, P.
1928. THE INFERIOR-SPECIES PROBLEM IN THE NORTHERN ROCKY MOUNTAINS. Jour. Forestry 26: 591–599.
(26) OGLESBY, C. V.
1926. DEFECT OR ROT IN FIR TIMBER. Timberman 27 (12): 186.
(27) SAXTON, J. B.
1918. WIND SHAKE IN DOUGLAS FIR TIMBER. Jour. Forestry 16: 734.
(28) SCHMITZ, H., and JACKSON, L. W. R.
1927. HEARTROT OF ASPEN WITH SPECIAL REFERENCE TO FOREST MANAGEMENT IN MINNESOTA. Minn. Agr. Expt. Sta. Tech. Bul. 50, 43 p., illus.
(29) SURI, PARMA NAND.
1926. TRAMETES PINI ON DEODAR IN THE BASPA VALLEY, BURSHAHR STATE, PUNJAB. Indian Forester 52 (7): 327–330, illus.
(30) UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE.
1928. INSTRUCTIONS FOR THE SCALING AND MEASUREMENT OF NATIONAL-FOREST TIMBER. 103 p., illus. Washington, D. C.
(31) WAGENER, W. W.
1928. BREAKAGE LOSS IN LOGGING. Jour. Forestry 26: 639–648.
(32) YOUNITZKY, A. A.
1927. INFECTION OF THE HEALTHY AND SCORCHED LIGNINE IN THE FORESTS OF MARY PROVINCE ON DATA OF THE MARY EXPEDITION. [In Russian, with an English resumé.] Izv. Kazansk. i Lesov. (Nachr. Inst. Land- u. Forstw. Kazan) 3(1): 98–117.

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PROPERTIES OF WESTERN LARCH AND THEIR RELATION TO USES OF THE WOOD

BY

R. P. A. JOHNSON
Engineer, Forest Products Laboratory

AND

M. I. BRADNER
In Charge, Office of Forest Products, Region I
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INTRODUCTION

Western larch [3] while well known in the "Inland Empire" [4] is not so well known in other sections of the United States. It is a comparatively new species in the lumber yards of New England, the

[1] Maintained by the U. S. Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin.

[2] The writers are indebted to S. V. Fullaway, formerly of the Forest Service, for much of the information on forest conditions, manufacturing practices, grade production, and distribution of lumber, and to E. M. Davis, Forest Products Laboratory, for the tables showing the annual ring growth, heartwood content, and characteristic defects of western larch. In addition, acknowledgment is made of assistance received from many other members of the Forest Products Laboratory staff, from the Western Pine Manufacturers' Association, and from the Potlatch Lumber Co.

[3] The standard names employed by the Forest Service for lumber and for the trees from which it is cut are used throughout this bulletin (*24*).[5] Other common names of the same species are given in the Appendix.

[4] Northwestern Montana, Idaho north of the Salmon River, Washington east of the Cascade Mountains, and the northeastern tip of Oregon.

[5] Italic numbers in parentheses refer to Literature Cited, p. 91.

Mississippi Valley, and the Rocky Mountain region, where most of the cut leaving the "Inland Empire" is now marketed. The wood has a combination of properties that adapts it to a wide variety of uses. Until the properties of western larch are better known the marketing of the wood will be handicapped, especially in new fields. The purpose of this bulletin is to present the available data on the properties and characteristics of western larch for the assistance of users in determining the suitability of the species for specific uses.

Determination of the suitability of a wood for any purpose can not, however, be based on properties alone. Such things as grade, size, and dryness must also be considered. For example, a species selected on the basis of the properties alone may be sold on the local market in substandard sizes or insufficiently dried, and the advantages inherent in the clear wood of the species may under such conditions disappear or be reversed.

It would appear, therefore, that to determine the suitability of western larch for any use information on the characteristics of the lumber, as well as on the properties of the clear wood, should be presented. To a limited extent such data are presented in this bulletin. It is not practical, however, to present complete and final data on all the characteristics of lumber, for they differ with time and place and are subject to change. The inherent properties, on the other hand, do not change with time and place. A comparison based on the properties of clear wood is, therefore, as good in Spokane, Wash., as it is in Baltimore, Md., and, except for slight changes that may result from more complete data, will be as good 10 years hence as it is to-day. This is not true of comparisons of grades, manufacturing defects, moisture content, sizes, and other similar factors. They are constantly changing, and will differ with localities. Thus, the lumber of a species that is commonly sold wet at present may be marketed thoroughly dry next year, or it may commonly be marketed wet along the Atlantic and Pacific coasts and dry in the Middle West.

For most uses any one of a number of species of wood may be used with equal satisfaction provided provision is made to compensate for differences in properties. Such compensating provisions may be made by the use of preservatives or other treatment, choice of sizes, or variations in design. Preservative treatments tend to equalize decay resistance, choice of sizes can be made to compensate for differences in strength, and design can be used to compensate for many of the differences in properties. The determination of the most suitable species, therefore, consists largely of determining the cost of the lumber and construction plus the cost of the necessary compensational measures for the species available. Where compensating measures are not used it is necessary to balance the total cost in place against the service and degree of satisfaction that can be obtained with different kinds of wood.

THE LARCH-FIR MIXTURE

Western larch is associated with Douglas fir ("Inland Empire" type)[6] both in the forest and in the lumber markets. The stand of

[6] Owing to differences in properties, Douglas fir (*Pseudotsuga taxifolia*) has been separated in this publication according to the locality where grown into three types, namely, Douglas fir ("Inland Empire" type), Douglas fir (coast type), and Douglas fir (Rocky Mountain type).

each species within the botanical range of western larch is about equal. (Fig. 1.) In individual stands, however, the proportion varies from one extreme to another. It is the general practice to mix the two woods and sell them as a single product under the commercial name larch-fir. The average annual lumber cut from 1919 to 1928, inclusive, shows the larch-fir mixture to be in round numbers 60 per

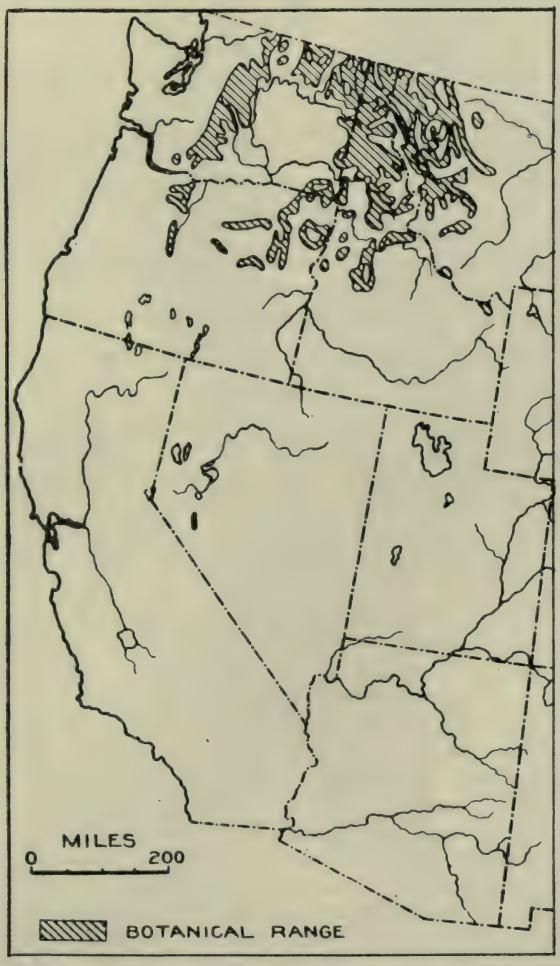


FIGURE 1.—Western larch (*Larix occidentalis*) botanical range

cent western larch and 40 per cent Douglas fir. The average proportion of western larch and Douglas fir ("Inland Empire" type) found in the different grades is given on page 49.

There are advantages and disadvantages in the mixing of species. The advantages lie in the savings in sorting, handling, and storage costs which accrue to the manufacturer. The disadvantages result from differences in properties, such as strength, color, and hardness, which are objectionable in some uses. In the common and dimension grades the advantages outweigh the disadvantages with the

manufacturer. Unless a decided preference develops for one of the woods in these grades, there is little chance of a change in the commercial practice of mixing the species. In the select grades there has developed a decided objection to the difference in the properties of the two species in the larch-fir mixture, especially color, percentage of sapwood, and hardness. The preference is for the western larch. Some manufacturers are meeting these objections by separating the species in the select grades. The continuation and extension of the practice of separating the species in select grades is necessary if western larch is to hold the reputation it has obtained in a number of uses.

The practice of mixing western larch with Douglas fir ("Inland Empire" type) makes it desirable to present the data in such form that the suitability of a mixture of the two species for any use may be determined. To accomplish this, western larch is taken as the basis of all comparisons of species. Data for Douglas fir ("Inland Empire" type) are also presented and compared with data on western larch. From the two sets of figures it will not be difficult to evaluate any mixture of larch-fir that may be encountered.

CHARACTER AND RANGE OF THE WESTERN LARCH FOREST

OCCURRENCE

Western larch grows chiefly in the drainage of the upper Columbia River. Its natural range extends from southern British Columbia to the western slopes of the Continental Divide of northern Montana and to the eastern slopes of the Cascade Mountains of Oregon (*24*). (Fig. 1.) It grows on mountain slopes, stream bottoms, valleys, and flats, preferring north and west exposures and elevations between 2,000 and 7,000 feet.

Western larch reaches its best development in northeastern Washington, northern Idaho, and northwestern Montana, where it often occurs in pure open forests, in valleys, and on slopes. (Fig. 2.) It is, however, usually associated with other species. In northern Idaho trees of the largest size are found at the lower elevations in mixture with western white pine, western hemlock, Engelmann spruce, and lowland white fir. Somewhat higher up it becomes an important part of the Douglas fir ("Inland Empire" type) forests, where it is associated with lodgepole pine, lowland white fir, alpine fir, and Engelmann spruce. The western larch-Douglas fir type occupies an intermediate position between the western yellow pine and subalpine types in northwestern Montana. The distribution of western larch has been increased by fires, and natural reproduction on burns is either in pure stands or in mixture with Douglas fir and lodgepole pine. The species is favored by burns because it requires a large amount of light and its seedlings can not obtain sufficient light to survive under the parent stand. Cutting and burning remove the advantage which the more tolerant associated species have in the forest.

CHARACTER

The western larch is one of the largest trees native to the region in which it grows. (Fig. 3.) It develops a straight, tall stem, occasionally attaining a height of 200 feet and a diameter breast high of 5 feet (*10*). The average height at maturity is 175 feet; the aver-

age diameter breast high is 20 inches. The trees average from five to six logs per tree. The average clear length of the stem varies from one and one-half logs in eastern Washington to three logs on the better white pine sites in Idaho. Stands per acre range from

FIGURE 2.—Dense stand of western larch. The tall, straight timber makes possible the production of a high percentage of clear lumber

about 2,000 feet, board measure, in the western yellow pine type of eastern Oregon, to 10,000 or 12,000 feet, board measure, in the larch-fir type of western Montana. Six to fifteen logs from an average stand will produce a thousand board feet of lumber. The average commercial stand of western larch is of good quality and yields a high percentage of select grades.

Western larch does not grow well in the shade. As a result the trees prune themselves of lower branches at an early age. The fire resistance of the western larch tree, which is due to the great thickness of its bark, is higher than that of any of the other Rocky Mountain

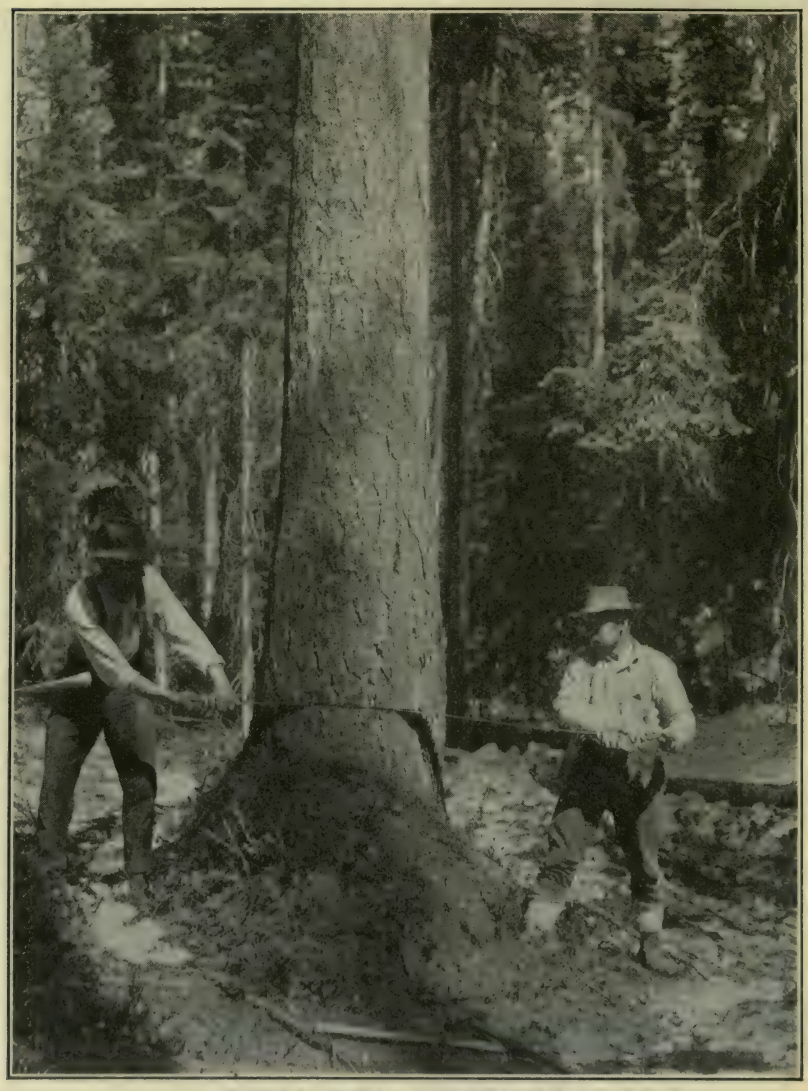


FIGURE 3.—Felling a western larch tree

conifers. This characteristic makes western larch a very suitable tree to reserve for seed so as to insure the stand against fire.

Western larch trees favorably located begin to bear seed at the age of 50 to 60 years and continue to bear good crops at intervals of five or six years. The germination of seed is prompt. The seedlings originate almost entirely from trees or stands left after cutting

or after burns, and germination and seedling growth take place generally on burned mineral soil or scorched duff surfaces.

Western larch trees are subject to the attack of a number of wood-destroying fungi, the most common of which is the chalky quinine fungus, *Fomes laricia*. The fungus causes a very destructive heart rot commonly known as brown trunk rot. Shake is a rather common and characteristic defect of the tree. It is confined, however, largely to the butt log. Consequently much of the shaky material is left in the woods as a result of the common practice of "long butting." Shake, rot, and other defects may cause a cull as high as 15 per cent in mature and overmature stands. The average run of large logs delivered at the mill in 1924 was 3.7 per cent defective.

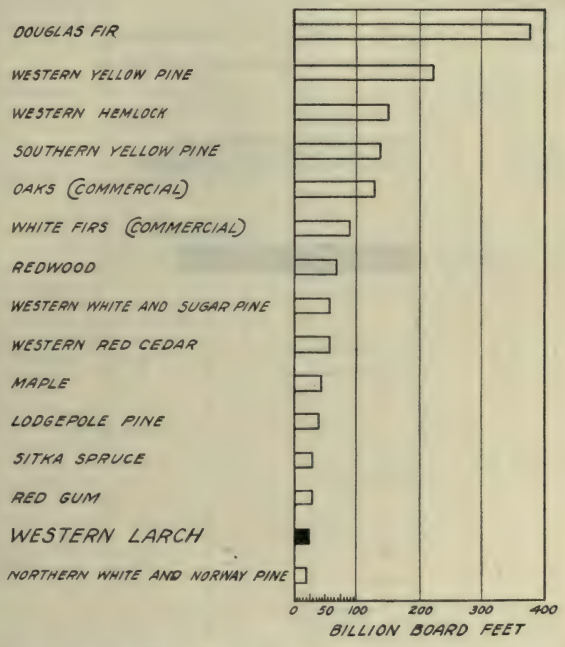


FIGURE 4.—Comparison of the present stand of western larch with that of 14 other species, based on 1923 estimates (*1*) revised for cut and growth to January 1, 1930. Other common names of the above species are given in the appendix

SIZE OF STAND

The total stand of western larch in the United States and Canada was estimated in 1923 for the United States Senate Select Committee on Reforestation (1) to be approximately 27,000,000,000 feet, board measure. Thirteen per cent of the western larch is located in the Canadian Province of British Columbia. The great majority, approximately 23,500,000,000 feet, is within the United States. Of this 23,500,000,000, 45 per cent is found in western Montana, 27 per cent in northern Idaho, 18 per cent in eastern Oregon, 8 per cent in eastern Washington, and the remaining 2 per cent is found in Idaho south of the Salmon River. The stand of Douglas fir in Idaho and Montana was estimated in 1923 to be approximately 30,000,000,000

feet, board measure, making a total of 53,500,000,000 feet of larch-fir in the United States.

Western larch makes up about 1 per cent of the total saw timber in the United States. The present stand of western larch is exceeded in volume by 3 hardwoods and by 10 softwoods. (Fig. 4.) An analysis of the timber resources of the "Inland Empire" shows that the stand of western larch is exceeded only by western yellow pine and Douglas fir ("Inland Empire" type). (Fig. 5.)

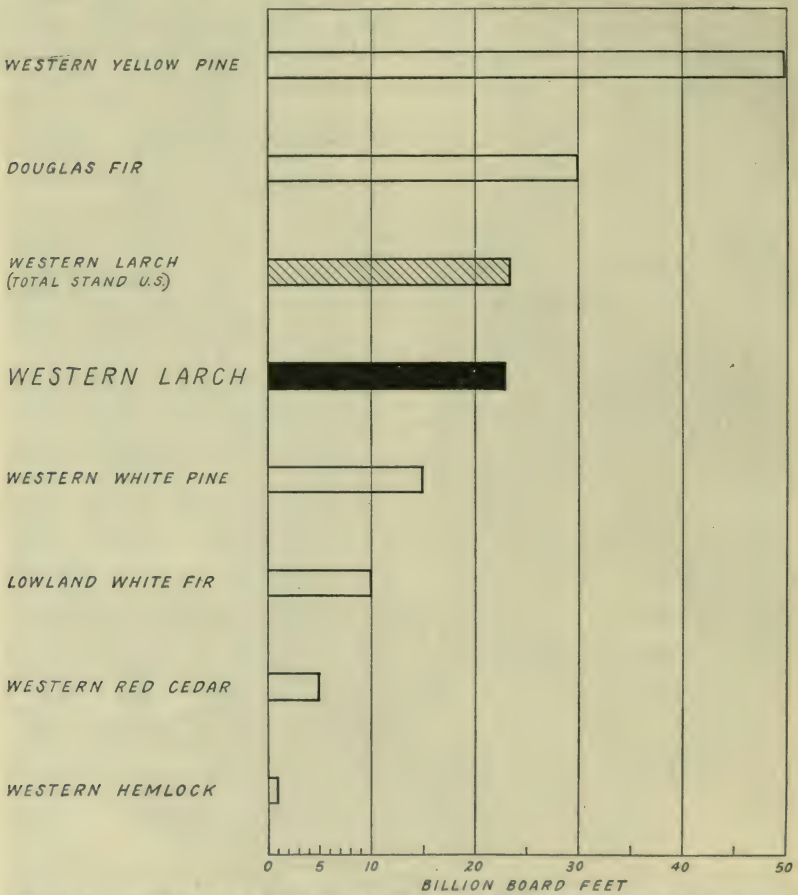


FIGURE 5.—Comparison of the stand of western larch with that of other species in the "Inland Empire." Other common names of the above species are given in the appendix

On the score of accessibility, western larch compares favorably with any of the other commercial species within the "Inland Empire" region. The western larch and larch-fir types of western Montana are in a large degree readily accessible at this time. Where larch is associated with the western white pine and western yellow pine, transportation facilities are continually improving as extensions are made to reach the pines. With the development of a greater demand for western larch at prices that will return a reasonable profit, a constant and adequate supply will be forthcoming.

CUT AND SUPPLY

The annual cut of western larch for 1929 was estimated to be 335,000,000 feet, board measure, log scale. This estimate includes the cut of western larch in the form of all products, reduced to board measure and is given on a log-scale basis to afford an easy comparison with stand figures. Of the total cut, 80 per cent is taken out in the form of saw logs; 7 per cent as hewed ties; 2 per cent as round, hewed, or split mine timbers; 1 per cent as posts, poles, and piling; and 10 per cent as cordwood. Montana furnishes approximately 39 per cent of the yearly cut, while Idaho, British Columbia, Washington, and Oregon contribute 28, 15, 13, and 5 per cent, respectively. In as much as larch and Douglas fir are commonly sold in mixture the corresponding production of Douglas fir is of interest. Within the larch-producing region it is roughly estimated that the annual

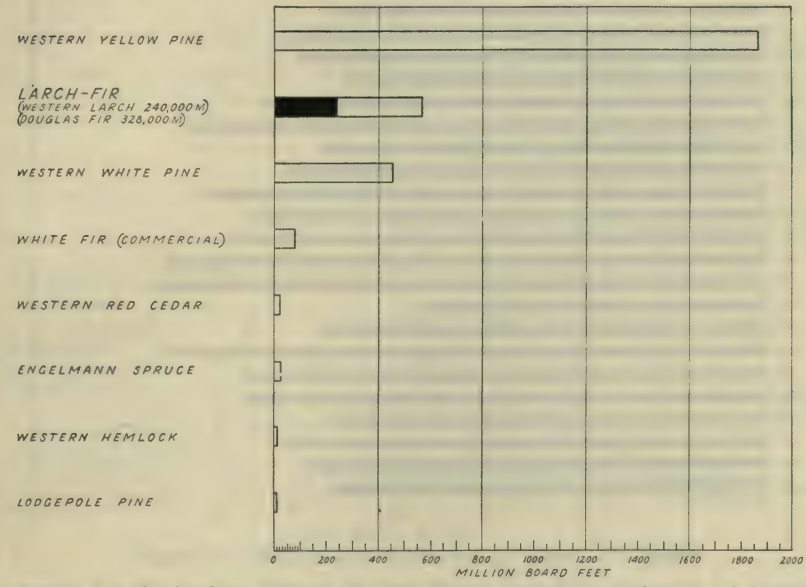


FIGURE 6.—The larch-fir mixture in 1926 ranked second in production of lumber in the "Inland Empire." Other common names of the above species are given in the appendix

cut of Douglas fir in 1929 amounted to 300,000,000 feet log scale. This means a yearly larch-fir cut of 635,000,000 feet, board measure. A comparison of the larch-fir lumber cut with the cut of the other principal lumber-producing species of the "Inland Empire" is shown in Figure 6.

There was a general increase in the production of western larch lumber from 1905 to 1920. (Fig. 7.) After the economic depression in 1921 the cut tended to stabilize around one-quarter of a billion board feet. It shows no tendency at present to shift materially from that figure. The cut of the species from 1905 to 1929 is shown by years in Figure 7.

The cut of western larch in 1928 was about 1 per cent of the total softwood lumber cut of the United States. In Idaho and Montana, where in 1928 80 per cent of the western larch lumber was cut, it con-

stituted 14½ per cent of the total lumber cut in those States. The remaining 20 per cent of the western larch cut came from Washington and Oregon. The 5-year average (1925 to 1929) cut, by States, was as follows:

State	Cut (thousand board feet)
Montana	119,850
Idaho	88,121
Washington	36,353
Oregon	12,146
Total	256,470

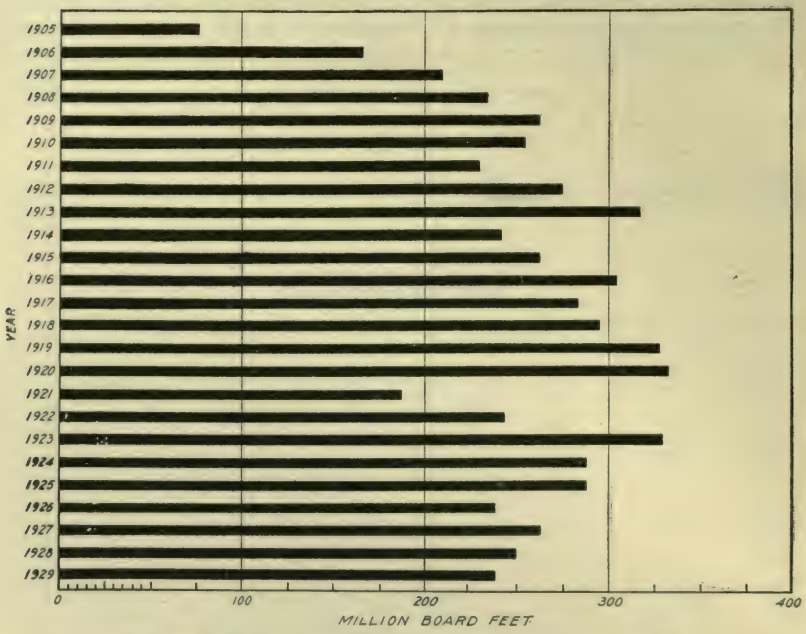


FIGURE 7.—Yearly lumber cut of western larch, 1905–1929

MERCHANDISING PRACTICES

DISTRIBUTION

The practice of using western larch as a filler in less-than-carload lots has been an important aid in enabling the species to enter new markets. Western larch first entered many of the eastern lumber yards, especially those in New England, as a filler in less-than-carload orders of western white and western yellow pine. The species found favor with many users, with the result that at present over one-fourth of the select grades of western larch are marketed in New England and in States along the Atlantic coast.

Sales of larch-fir direct to the consumer consist largely of ties and other railroad material, mine timbers, and some box and crating stock. At mills located within the larger centers of population, plant retail departments dispose of considerable larch-fir direct to the

user. Such local sales have resulted from the desire to have local consumption absorb the woods that have a low mill run value and are, therefore, less able to stand the freight charges to distant markets.

The bulk of the larch-fir yard lumber is used in the Mississippi Valley. The bulk of planks and timbers and miscellaneous items is used in the "Inland Empire." The distribution of the larch-fir cut to various consuming regions is shown in Table 1, which is based on the distribution of the cut produced by members of the Western Pine Manufacturers' Association. A general idea of the distribution of some of the more important products of larch-fir may be obtained from Table 2, which is an analysis of the distribution of the different larch-fir products shipped during a 12-month period by one mill. A surprisingly large percentage of the larch-fir cut is sold direct to the retailer, especially west of the Mississippi River.

TABLE 1.—*Distribution of larch-fir lumber*

[Based on 1924 shipments of members of the Western Pine Manufacturers' Association]

Grade	"Inland Empire"[1]	Rocky Mountains[2]	Mississippi Valley, west[3]	Mississippi Valley, east[4]	Atlantic coast[5]
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Selects	7	1	26	39	27
Nos. 1 and 2, common	11	9	41	34	5
No. 3, common	10	5	59	24	2
Nos. 4 and 5, common	10	2	58	28	2
Thick, common	31	10	2	56	1
Dimension	21	10	44	25	----------
Planks and timbers	59	11	21	8	1
Miscellaneous	63	8	26	3	----------
Battens and molding	2	----------	12	3	83
Lath: 5-year average	8	1	40	39	12

[1] Idaho, Montana, Oregon, Washington.
[2] Colorado, Wyoming, Utah, New Mexico, Nevada.
[3] The Dakotas, Minnesota, Iowa, Kansas, Nebraska, Missouri, Texas, Oklahoma, Arkansas.
[4] Illinois, Michigan, Wisconsin, Ohio, Indiana, and Southern States.
[5] Pennsylvania, Delaware, New Jersey, New York, Maryland, District of Columbia, and other Eastern States.

TABLE 2.—*Distribution of larch-fir products by regions*

[Based on shipments from 1 mill for 1924]

Region to which shipped	Products					
	Vertical-grain flooring	Surfaced, 2 sides and center, matched flooring	Ceiling or partition	Drop siding and rustic ship-lap	Car siding and lining	Boards, square edged
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
"Inland Empire"	12	26	17	43	----------	24
Rocky Mountains	----------	----------	----------	(1)	100	11
Mississippi Valley, west	5	23	15	24	----------	46
Mississippi Valley, east	11	35	25	20	----------	17
Atlantic coast	72	16	43	13	----------	2
Total	100	100	100	100	100	100

[1] Less than 1 per cent.

PERCENTAGE OF CUT GOING INTO VARIOUS LUMBER ITEMS

More larch-fir goes into dimension, ties, and timbers than into all other items combined. About one-third of the total cut goes into No. 1 dimension, over a third of which is 2 by 4 inches in size.

Table 3 gives in detail the larch-fir shipments reported to the Western Pine Manufacturers' Association by association mills during 1928.

TABLE 3.—*Details of larch-fir shipments by members of Western Pine Manufacturers' Association, 1928*

Grade and size	Thousand board feet	Per cent
No. 1 Dimension:		
2 by 4 inches	10,520	
2 by 6 and 2 by 8 inches	9,512	
2 by 10 inches	3,158	
2 by 12 inches	3,626	
2 by 14 inches and wider	48	
Resawn	40	
Total	26,904	37.8
No. 2 Dimension:		
2 by 4 inches	1,681	
2 by 6 and 2 by 8 inches	977	
2 by 10 inches	210	
2 by 12 inches	479	
Resawn	519	
Total	3,866	5.4
No. 3 Dimension:		
2 by 4 inches	821	
2 by 6 and 2 by 8 inches	374	
2 by 10 inches	4	
2 by 12 inches	20	
Resawn	236	
Total	1,455	2.0
No. 1 Timbers:		
3 by 4 inches	11	
3 by 6, 4 by 4, and 4 by 6 inches	1,323	
3 by 8, 4 by 8 inches	71	
3 by 10 and 3 by 12 inches, 4 by 10 and 4 by 12 inches	1,513	
6 by 6 to 8 by 10 inches	440	
6 by 12 to 8 by 12 inches	22	
10 by 10 to 12 by 12 inches	46	
Larger than 12 by 12 inches	15	
Total	3,441	4.8
No. 2 Timbers	19	.0
Ties	1,306	1.8
No. 1 and 2 Common:		
4 inches	147	
6 inches	1,159	
8 inches	387	
10 inches	130	
12 inches	115	
5/4-inch	52	
Total	1,990	2.8
No. 3 Common:		
4 inches	1,732	
6 inches	2,702	
8 inches	2,279	
10 inches	831	
12 inches	538	
Mixed widths	62	
5/4 inch	42	
Total	8,186	11.5
No. 3 and Better Common:		
4 inches	1,249	
6 inches	2,491	
8 inches	1,558	
10 inches	489	
12 inches	646	
Mixed widths	3	
Total	6,436	9.0
No. 4 Common	8,049	11.3
No. 5 Common	443	0.6
Short Common	494	0.7
Select Common	514	0.7
C and Better Vertical-grained Flooring:		
4 inches	601	
3 inches	103	
Total	704	1.0
C and Better Flat-grained Flooring:		
4 inches	789	
6 inches	412	
Total	1,201	1.7
C and Better Drop Siding or Rustic:		
4 inches	28	
6 inches	1,181	
Total	1,209	1.7
C and Better Ceiling:		
4 inches	336	
6 inches	297	
5/8 inch	574	
Total	1,207	1.7
C and Better Finish:		
4 inches	201	
6 inches	156	
8 inches	122	
10 inches	107	
12 inches	48	
13 inches and wider	2	
Thick	393	
Total	1,029	1.5
D Vertical-grained Flooring:		
4 inches	39	
3 inches	6	
Total	45	0.1
D Flat-grained Flooring:		
4 inches	295	
6 inches	227	
Total	522	0.7

TABLE 3.—*Details of larch-fir shipments by members of Western Pine Manufacturers' Association, 1928*—Continued

Grade and size	Thousand board feet	Per cent	Grade and size	Thousand board feet	Per cent
D drop Siding or Rustic:			D Finish—Continued.		
4 inches	10		10 inches	5	
6 inches	458		12 inches	1	
			Thick	11	
Total	468	0.7			
			Total	215	0.3
D Ceiling:					
4 inches	51		D and Better Finish:		
6 inches	44		All widths	637	
5/8 inch	72		Thick	286	
Total	167	0.2	Total	923	1.3
D Finish:			Short Select	72	0.1
4 inches	152		Miscellaneous	435	0.6
6 inches	38				
8 inches	8		Total, all grades	71,300	100.0

DESCRIPTIVE PROPERTIES OF WESTERN LARCH

GENERAL DESCRIPTION OF THE WOOD

The wood of western larch closely resembles that of Douglas fir (coast type). Described in standard terms (*16*), the wood is moderately heavy, strong, moderately hard, moderately high in shock resistance, stiff, and has a moderately high shrinkage. It is moderately decay resistant, slightly resinous, has no distinctive odor or taste, and has alternate bands of hard and soft wood. These characteristics are all relative and can be applied equally well to the coast type of Douglas fir, except that Douglas fir is resinous and very stiff. The paint-holding characteristics of the two species are likewise very similar.

Western larch, however, has a number of distinctive characteristics. The heartwood is a dark reddish brown, and the sapwood a light straw color and very narrow (*12*). The annual rings in western larch are exceptionally narrow and uniform in width. This characteristic is sufficiently pronounced to produce a distinctive figure which the lumber trade describes as "wire grained." The wood is exceptionally slow in giving up and taking on moisture. Its slowness in giving up moisture has resulted in much of the wood being marketed before it was properly seasoned, although if exposed long enough to uniform conditions western larch will eventually reach about the same moisture content as will other woods. On the other hand, once properly seasoned, its slowness in picking up moisture is a distinct advantage. A much more detailed description of these and other properties and characteristics of species follows.

HEARTWOOD CONTENT OF LUMBER

The heartwood content of western larch is high because the sapwood is usually only from one-half to three-fourths of an inch thick and consequently is largely cut off with the slab. A study made by the Forest Products Laboratory on western larch boards 8 inches wide showed the sapwood to occupy less than 5 per cent of the area

of the best face. From 60 to 70 per cent of the boards studied, depending on the grade, contained no sapwood. A somewhat higher percentage of sapwood was found in narrower boards, and a somewhat smaller percentage in wider boards.

The Douglas fir ("Inland Empire" type) has a wider sapwood ring than western larch. Generally the sapwood ring in a Douglas fir log is over 1 inch wide (*12*). On an average sapwood occupied about 12 per cent of the best face of the Douglas fir ("Inland Empire" type) lumber studied. Over 90 per cent of the Douglas fir ("Inland Empire" type) boards contained two-thirds or more of heartwood. The amount of heartwood in the larch-fir mixture, though containing less heartwood than western larch, compares favorably with most commercial species.

GROWTH RINGS

Western larch is one of the slowest growing commercial softwoods; consequently, the annual rings are very narrow and uniform in width. Studies by the Forest Products Laboratory show that 1-inch western larch lumber averaged 25 rings to the inch, Douglas fir ("Inland Empire" type) averaged 18, Douglas fir (coast type) 13, virgin commercial longleaf pine 20, and mixed virgin and second-growth commercial shortleaf pine 8 rings per inch. Ninety-two per cent of the western larch pieces studied had over 13 rings per inch. In thicker stock the average number of rings may be slightly less than for 1-inch lumber, but the difference is not great, for the annual growth is narrow and uniform from close to the pith to the bark. The ring growth of the "Inland Empire" type of Douglas fir is wider and less uniform than that of western larch.

SUMMER-WOOD CONTENT

Western larch has pronounced alternate bands of hard summer wood and softer spring wood. The summer wood is darker in color than the spring wood and contrasts sharply with it. The summer-wood bands of western larch are narrow and contrast with the spring wood much like those in the commercial type of Douglas fir known as old-growth yellow fir. The summer wood in southern yellow pine is wider, more easily measured, and contrasts more pronouncedly with spring wood than that of western larch. The summer wood of eastern and western hemlock and white fir does not contrast so sharply with spring wood as that of western larch. The high percentage of summer wood in western larch is largely responsible for the weight, strength, and hardness of the wood.

FIGURE

The figure of western larch is pronounced. It is similar to that in Douglas fir, is not so pronounced as that in the southern pines, but is more pronounced than that of western hemlock and white fir. The narrow and uniform width of the growth rings has a marked influence on the figure, tending to soften the contrast resulting from the differences between the summer wood and spring wood. The characteristic figures of edge-grained and flat-grained material are shown in Plate 1.

HOW TO DISTINGUISH WESTERN LARCH FROM OTHER WOODS

The wood of western larch is comparatively easy to distinguish from the wood of all species except Douglas fir (all types), tamarack, southern cypress, and the southern yellow pine. Even the wood of these species can usually be distinguished from that of western larch by the unaided eye. Structural characteristics visible under the microscope make it possible to positively distinguish western larch from all species except tamarack (*12*). The distinguishing characteristics of western larch are the reddish-brown color of the heartwood, the narrow and evenly spaced annual rings, the contrast between summer wood and spring wood, narrow sapwood ring, the yellowish-white color of the sapwood, and the lack of pronounced odor or taste.

Douglas fir (all types) is the wood with which western larch is most likely to be confused. Confusion may occur not only because the two woods are very similar in appearance but also because western larch is sold in mixture with Douglas fir ("Inland Empire" type) and finds its way into many of the same markets and uses as Douglas fir (coast type). The easiest and most general method of distinguishing western larch from Douglas fir (all types) is by the difference in the color of the heartwood. Western larch heartwood has a marked brownish color in contrast with the reddish or yellowish color of Douglas fir. In addition western larch has a narrower sapwood ring, and as a result the lumber contains less sapwood. The annual rings of both species are relatively narrow and comparatively uniform in width. The rings in western larch, however, are more uniform in width and narrower than those of Douglas fir; this is especially true of the "Inland Empire" type of Douglas fir. The knots in western larch are generally smaller, tighter, and sounder than those of Douglas fir. Douglas fir has a distinct odor when freshly cut, while western larch is odorless. Lumber graders often use the greater weight of western larch as an aid in distinguishing it from the Douglas fir ("Inland Empire" type). None of these characteristic differences, however, is as reliable a basis for distinguishing the wood as is the structural difference visible under a microscope.

The wood of tamarack can not, with our present knowledge, be positively distinguished from that of western larch. Tamarack lumber in bulk, however, can usually be roughly distinguished from that of western larch by its wider and less uniform growth rings and more pronounced summer wood. Fortunately it is not often necessary to distinguish between these species, for they go into different markets and uses, and there is small chance of the lumber being mixed. In addition, the cut of tamarack is small, and it is commonly distributed in mixture with other woods, especially eastern hemlock. The mixture is easily distinguished from the larch-fir mixture.

The color of western larch sufficiently resembles that of southern cypress to cause occasional confusion. The wood of southern cypress, however, can be distingushed from that of western larch by the rancid odor, by the less uniform width of growth rings, and the wider sapwood of the southern cypress. In addition, the summer wood of southern cypress is usually less pronounced and does

not contrast so sharply with the spring wood. With a good magnifying glass western larch can be positively distinguished from southern cypress by the resin ducts which are present in western larch but not in cypress. Necessity for distinguishing between the species occurs when the two species go, as they occasionally do, into the same uses in the same markets. The confusion of the woods results from the use of names such as mountain cypress for western larch, as well as from similarity of color and general appearance of some select-grade material.

Western larch and the hard pines differ sufficiently in appearance so that only occasionally are specimens of one species likely to be mistaken for those of the other. The principal cause of confusion is the presence in both of pronounced alternate bands of hard and soft wood, combined with a general brownish color. The summerwood bands of western larch, however, are narrower and less pronounced than those of hard pines, and the brown of the heartwood is reddish in western larch and yellowish or orange brown in the hard pines. The wood of the hard pines is readily distinguished from western larch by the more resinous character, wider annual rings, more pronounced summer wood, and wider sapwood of the hard pines.

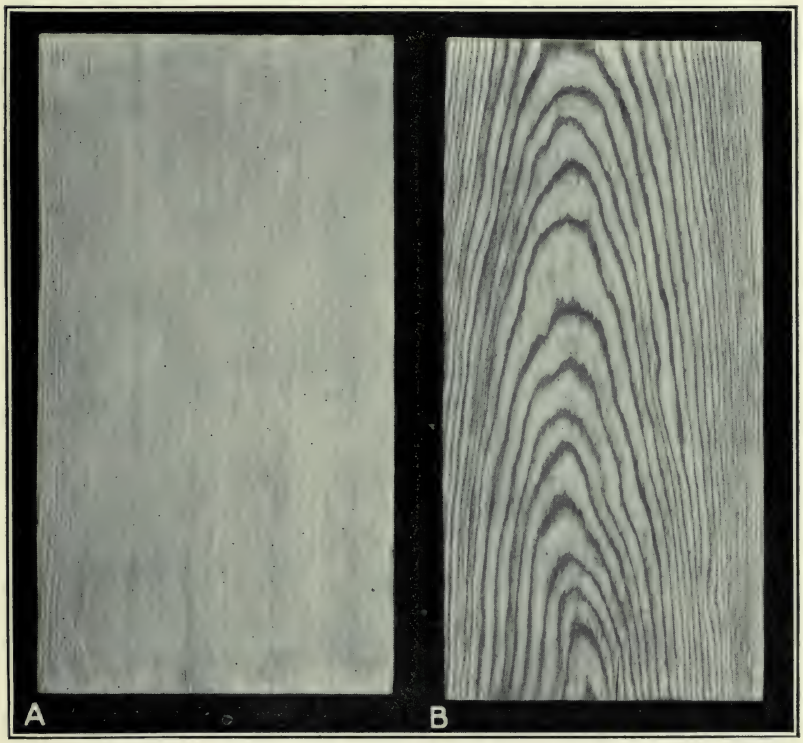
The comparisons just made of the wood of western larch with that of other species are intended as an aid in identifying western larch lumber in the bulk. The positive identification of individual specimens is more difficult. It quite often requires the use of the microscope which will reveal structural differences not visible to the unaided eye.[7] (Pl. 2.)

GRAIN AND TEXTURE

Western larch has been described as a "wire-grain" wood because of its uniformly narrow bands of hard and soft wood. (Pl. 1, A.) Western larch is also known as a "straight-grained" wood; that is, the wood is comparatively free from spiral grain and entirely free from interlocking grain. The amount of cross grain in western larch depends to some extent upon the taper of the logs and the methods employed in manufacturing, for cross grain is produced in sawing as well as in growth. The taper in western larch logs is usually less than 1 inch in 10 feet of length (*5*); consequently the amount of cross grain developed in sawing is small. Cross grain is objectionable because of its injurious effect on strength (*33*) and its tendency to cause warping.

In texture the wood of western larch is composed of pronounced alternate bands of summer wood and spring wood. The wood cells in the spring wood are larger and much thinner walled than in the summer wood. (Pl. 2.) As a result the summer wood is much harder, heavier, and darker than the spring wood. The contrast between summer wood and spring wood is not so pronounced as in southern yellow pine or in Douglas fir (all types), but is more pronounced than in the hemlocks, spruces, and true firs. The alternate bands of western larch are narrower and more uniform in width than in any of the species mentioned. The characteristically narrow bands

[7] Where the necessity for positive identification exists samples may be submitted for identification to the Forest Products Laboratory, Madison, Wis.



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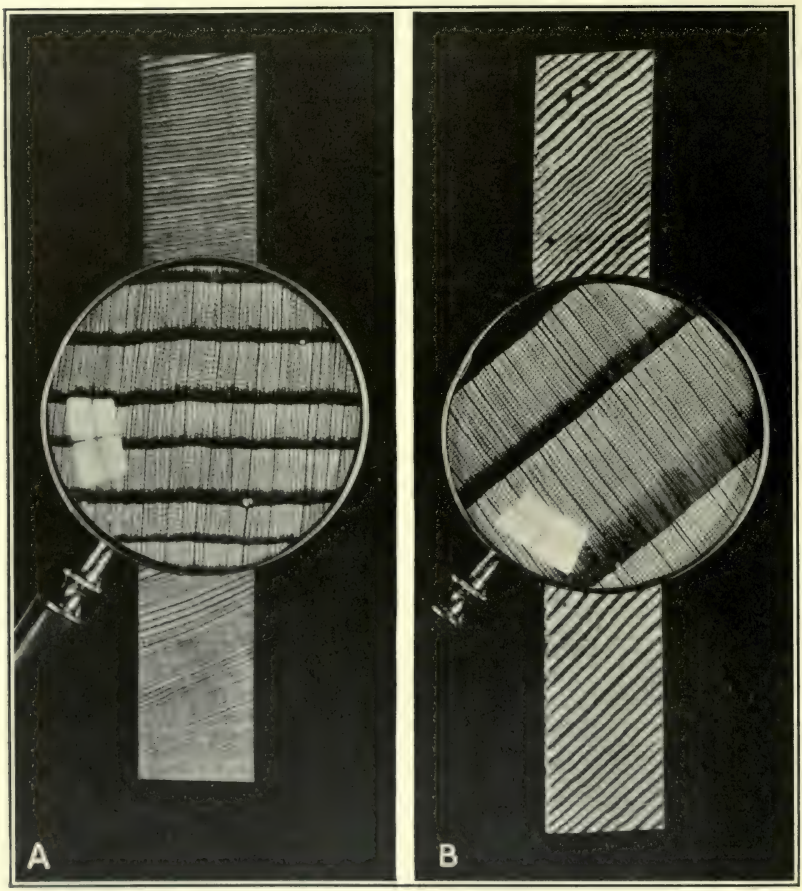
Characteristic figures of western larch. A, Edge-grained figure. The narrow uniform bands are sometimes termed "wire grain;" B, flat-grained figure. The narrow uniformly spaced bands of hard and soft wood account for the attractive figure in flat-sawn western larch



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End sections of western larch and Douglas fir as they appear when highly magnified. A, Western larch. The pronounced alternate bands of dark summer wood and light spring wood and scattered small resin ducts shown by white spots are characteristic of the species; B, Douglas fir. The same pronounced summer-wood and spring-wood bands as in western larch are also in Douglas fir, but they are generally wider in the Douglas fir

of western larch reduce the tendency to deflect nails that is sometimes encountered in species with wide and pronounced summerwood bands.

MECHANICAL AND PHYSICAL PROPERTIES

Wood users generally evaluate a species in terms of other species. Tough like ash, strong like oak, cuts like white pine, are typical examples. Since this is the common and familiar method of judging the value of species, a comparison of the properties of western larch with those of other well-known woods is made in this publication. Western larch is represented as 100 points in order that comparisons may be made with other species by a glance at the table or figures. As previously pointed out, such comparisons are of the average inherent properties of the clear wood and hold only when other things, such as defects, moisture content, size, and the like, are equal.

Average values alone are not always adequate for the selection of species, for individual pieces may vary widely from the average. Knowledge of the probable extent of the variation from the average is therefore often of value. There is about a 50–50 chance that any individual piece of western larch selected at random will not vary from the average more than the percentage shown in the bottom line of figures in Table 4 (*15*). In other words, in any shipment about half of the material will not vary from the average more than the percentage shown. For example, the probable variation in bending strength, bottom line of column 6, Table 4, is 12 per cent. It is estimated, therefore, that the bending strength of one-half of the pieces of western larch will fall between 88 and 112.

The strength values for western larch are based on approximately 2,500 tests. The test specimens were obtained from three localities scattered throughout the range of the species in the United States. Additional tests of western larch would probably not change the average values more than 3.1 per cent in shock resistance and 1.3 per cent in specific gravity. Change in other properties would fall between these two extremes. The probable change in the other species as a result of additional tests will in no case exceed 5 per cent in toughness and 2.1 per cent in specific gravity. In many of the species where from two to three times as many tests have been made as in western larch the probable changes in the average value would be even smaller than in western larch (*15*).

In addition to the testing done at the Forest Products Laboratory considerable testing of western larch has been done by the Canadian Forest Products Laboratory (*13*, *23*).

Values in Table 4, with the exceptions of the white oaks and eastern spruce, are for a single botanical species. The figures for commercial white oak are the average of six species that are marketed under the name white oak. These six species of oak are so closely related that they can not be distinguished from one another by an examination of the wood alone. Red spruce and white spruce are also closely related species, very similar in their properties, and are not separated commercially. They are sold under the commercial name of eastern spruce.

TABLE 4.—*Average mechanical and physical properties of the clear wood of western larch compared with other species* [1]

Species of wood [2]	Specific gravity based on weight when oven dry and volume when green	Weight per cubic foot		Composite or index values [3] (western larch taken as 100 points) for—						Strength at 12 per cent moisture content	
		Green	At 12 per cent moisture content	Shrinkage	Bending strength	Compressive strength (endwise)	Stiffness	Hardness	Shock resistance	Modulus of rupture	Compression parallel to grain
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
		Pounds	*Pounds*	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Larch, western (Larix occidentalis)	0.48	48	36	100	100	100	100	100	100	11,790	7,480
Cedar, western red (Thuja plicata)	.31	27	23	59	67	71	71	59	64	7,800	5,120
Cypress, southern (Taxodium distichum)	.42	50	32	81	89	89	89	81	94	10,610	6,390
Douglas fir (Pseudotsuga taxifolia) (coast type)	.45	38	34	94	101	103	118	92	100	12,270	7,650
Douglas fir (Pseudotsuga taxifolia) ("Inland Empire" type)	.41	37	31	87	90	87	104	91	89	11,450	6,800
Douglas fir (Pseudotsuga taxifolia) (Rocky Mountain type)	.40	35	30	80	84	80	93	81	83	9,650	6,140
Hemlock, eastern (Tsuga canadensis)	.38	50	28	76	81	76	79	80	83	8,950	5,490
Hemlock, western (Tsuga heterophylla)	.38	41	29	93	83	81	94	78	90	9,990	6,200
Oaks, commercial white (average of six species) [4]	.59	63	47	120	111	89	97	170	154	13,990	7,060
Pine, loblolly (Pinus taeda)	.50	54	38	98	104	100	109	97	115	13,000	8,200
Pine, longleaf (Pinus palustris)	.55	50	41	96	119	118	124	119	127	15,490	9,060
Pine, northern white (Pinus strobus)	.34	36	25	64	71	64	78	55	68	8,920	4,910
Pine, shortleaf (Pinus echinata)	.49	51	38	99	109	100	111	106	137	13,350	7,860
Pine, western white (Pinus monticola)	.36	35	27	91	78	72	90	55	80	9,650	5,720
Pine, western yellow (Pinus ponderosa)	.38	45	28	75	73	66	73	64	72	9,320	5,340
Redwood (Sequoia sempervirens) [5]	.41	55	30	50	101	100	88	92	86	10,800	6,600
Spruce, eastern (average of red and white)	.37	34	28	98	79	72	84	61	83	9,920	5,720
Tamarack (Larix laricina)	.49	47	37	99	94	92	96	83	105	11,700	7,170
Percentage estimated probable variation of an individual piece	8.0			12	12	14	18	16	20		

[1] This table is for use in comparing species either in the form of clear lumber or in grades containing like defects, except structural material. Structural material which conforms to American lumber standards should be compared by means of allowable working stresses, values for which are presented in Table 16.

[2] Other common names of the above species are given in the Appendix.

[3] For derivation of composite values see Markwardt (*15*).

[4] Bur oak, chestnut oak, post oak, swamp chestnut oak, swamp white oak, and white oak.

[5] The trees on which these values are based were somewhat higher in density than the general average for species. It is, therefore, probable that future tests which are now under way will slightly lower the present figures, although it is not expected that this will necessitate any change in the working stresses recommended for structural timbers as given in Table 16.

WEIGHT AND SPECIFIC GRAVITY

Western larch is a heavy softwood. In an air-dry condition (12 per cent moisture content) it weighs on an average 36 pounds per cubic foot. (Fig. 8.) Green, it will average 48 pounds per cubic foot. The weight of air-dry material varies with the density, regional climatic conditions, and size of the stock. In the North Central States the average moisture content of thoroughly air-dry western larch is about 12 per cent, and the average weight of thoroughly air-dry yard stock will therefore be 36 pounds per cubic foot. Because of variations in density, however, the average weight of the air-dry stock may vary from about 33 to 39 pounds per cubic foot. In a hot, dry climate, like that of the Southwest, the weight of thoroughly air-dry yard stock may drop as low as 32 pounds per cubic foot in a piece of low density because of the low moisture content common to

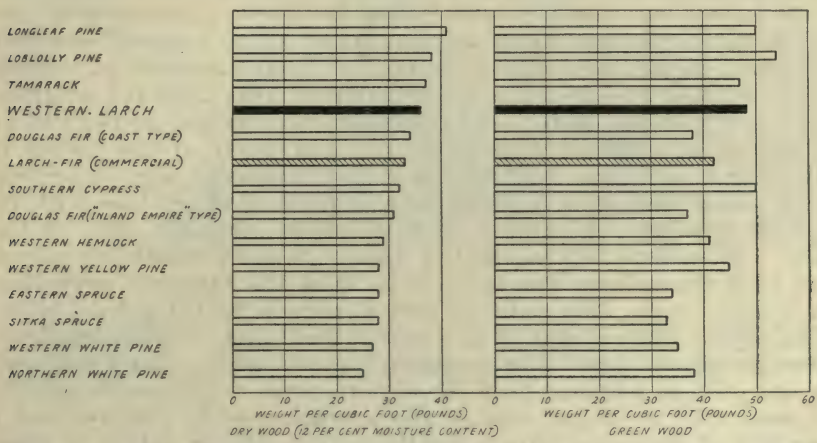


FIGURE 8.—Average weight per cubic foot of green and dry western larch compared with other species. The green weight may vary widely from the averages shown because of the wide range in the moisture content of green wood

that region. In a humid climate, on the other hand, the weight may run as high as 41 pounds per cubic foot in pieces of high density. Seasoned structural timbers average about a pound heavier per cubic foot than yard stock because they do not come to so low a moisture content as does yard lumber. Green western larch varies over a much wider range in moisture content than air-dry stock because of the large variations of the moisture in the living tree. Green western larch will seldom drop below 37 pounds per cubic foot but may occasionally go as high as 75 pounds per cubic foot.

A comparison of the weights per cubic foot of green and air-dry western larch and those of other species is shown in Figure 8. The weight of thoroughly air-dry western larch is between that of southern yellow pine, which is slightly heavier, and that of Douglas fir (coast type), which is slightly lighter. Douglas fir of the "Inland Empire" type is about 5 pounds to the cubic foot lighter than western larch. The practice of mixing western larch and Douglas fir of the "Inland Empire" type reduces the weight of the common grades of the larch-fir mixture from 2 to 4 pounds per cubic foot, depending on the percentage of Douglas fir present. The weight

of the larch-fir mixture shown in Figure 8 is based on a 50-50 mixture. In the select grades the weight of the species in mixture will seldom be more than a pound lighter than western larch because of the small percentage of the select grades obtained from Douglas fir ("Inland Empire" type). The weight of the larch-fir mixture in a green condition is materially lower than the weight of green western larch, especially in the common grades.

The specific gravity is another and useful measure of the weight of western larch. When oven dry, western larch has an average specific gravity of 0.48; that is, a cubic foot of western larch at practically zero moisture content weighs 0.48 of the weight of a cubic foot of water at 39.2° F. The specific gravity is therefore a measure of the amount of wood substance, and aside from actual tests is the best indicator of the strength as well as of a number of other properties of wood.

A survey was made by the Forest Products Laboratory of the range in specific gravity of western larch. Nine hundred and seventy-two samples were selected at random from shipments of western larch as they left the mills. The samples were collected at three mills and included material of the select and common grades and of a number of different mill products. The result of the survey is illustrated in Figure 9, which shows how a lumber pile of western larch would look if it were sorted and piled in accordance with its specific gravity. A smooth curve is drawn through each of the tiers. This curve is a variability curve. Similar variability curves are used throughout this bulletin to show the range in properties of western larch. The value of such a curve is that it gives a better idea of the general run of the species than can be obtained from average values alone. For example, Figure 9 shows that 1 per cent, or one piece in a hundred, of the western larch has a specific gravity of only 0.34, or 76 per cent of the average specific gravity, and 1 per cent of the pieces have a specific gravity of 0.58, which is about 29 per cent higher than the average specific gravity. Also, the lightest pieces have only about one-half the specific gravity of the heaviest. The curves at the end of the bars in subsequent figures may be considered as representing the end view of piles of lumber sorted in accordance with the property under consideration, just as in Figure 9.

A rough general comparison of the properties of western larch with those of other species can be made quickly by comparing their specific gravities. Figure 10 is a comparison of the average and range in specific gravity of western larch and six well-known species. The data on which the comparison is based was obtained from specimens selected at random from material as it left the mills. The average values and the range in values differ slightly from the data in Table 4 because of differences in method of selection and test. For example, the average specific gravity of western larch is shown as 0.48 in Table 4, based on selected samples from selected trees, and 0.45 in Figures 9 and 10, based on random selection of material as it went on the market.

BENDING STRENGTH

The clear wood of western larch has a high bending strength. Bending strength is a measure of the load-carrying capacity of clear wood when used as a beam. The bending strength of western larch

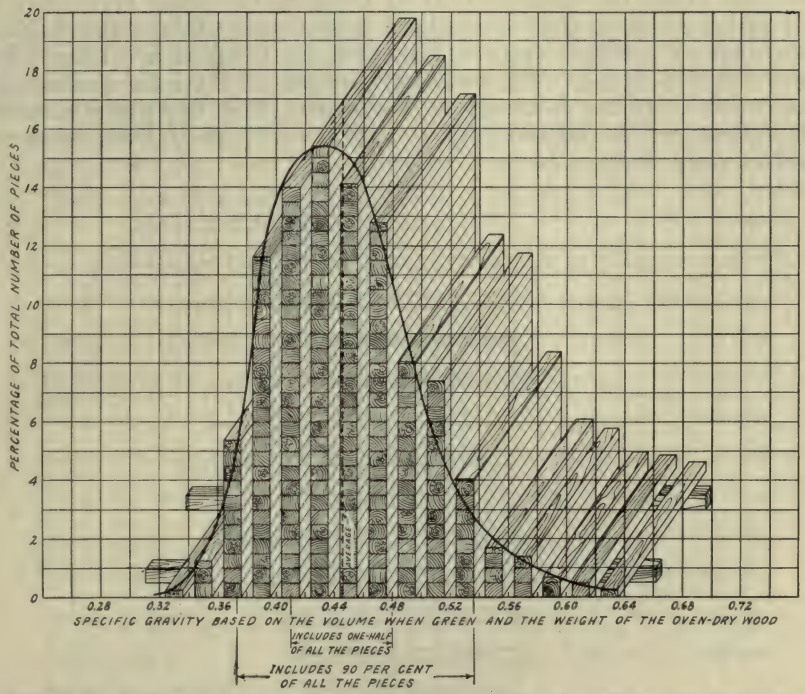


FIGURE 9.—Variations in specific gravity of western larch. The figure shows the form a pile of western larch would take if the pieces were sorted into groups in accordance with the specific gravity. It is based on results of determinations made on 972 samples selected at random from lumber as it left the mills

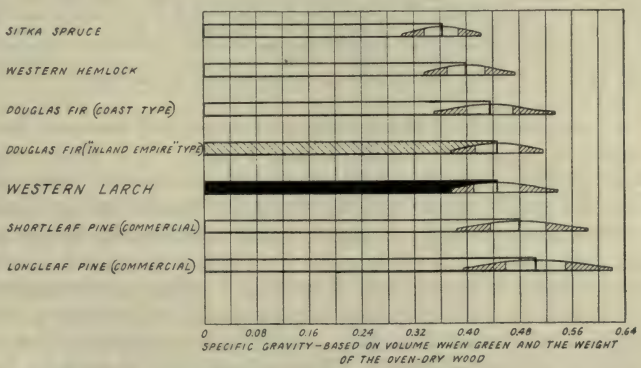


FIGURE 10.—Average specific gravity and range in specific gravity of western larch compared with other species of wood; based upon a random selection from siding, finish, common boards, dimension, flooring, chip-lap, and other items of lumber as shipped from the mills. Average shown by the end of the horizontal bar and range by the curve. One-half of all material of a species of wood fell within the range shown by the blank space between the crosshatched areas; 40 per cent in the range shown by the crosshatching, 20 per cent above the average, and 20 per cent below average; while 10 per cent, 5 per cent above and 5 per cent below, fell outside the range shown by the curve

averages about the same as that of Douglas fir (coast type) but is not quite so high as that of southern yellow pine. It averages higher than that of southern cypress, tamarack, or Douglas fir of the "Inland Empire" type. The bending strength of larch-fir mixture in the common grades is therefore lower than that for western larch. The select grades contain only a small percentage of Douglas fir or contain only western larch.

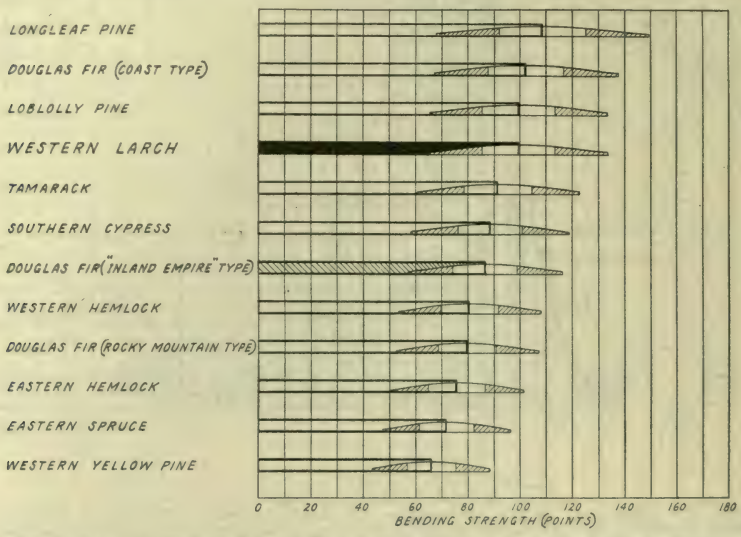


FIGURE 11.—Average and range in bending strength of clear wood of western larch as compared with that of other species of wood. The comparison shown here is for clear lumber. The effect of defects, difference in dressed dimensions, moisture content, or drying conditions may equalize or reverse the relative values as charted. Western larch taken as 100 points. Average is shown by the end of the horizontal bar and range by the curve. One-half of all material of a species of wood will fall within the range shown by the blank space between the crosshatched areas; 40 per cent in the range shown by the crosshatching, 20 per cent above the average and 20 per cent below the average; while 10 per cent, 5 per cent above and 5 per cent below, will fall outside the range shown by the curve

A direct comparison of the bending strength of western larch with other species is made in Table 4 and Figure 11. The comparison is of value in judging the suitability of species for uses requiring comparatively small, clear pieces, such as ladder steps, automobile decking, cross arms, wagon tongues, and automobile body parts.

Bending strength is one of several properties required in structural timbers for mines, bridges, and factories. Such structural material contains defects, and the bending strength of individual pieces is dependent more on the size, number, and location of the defects than on the strength of the clear wood. The suitability of western larch for structural purposes is therefore best determined from the working stresses (p. 58), which are based on comparable grades and which take into consideration the influence of the defects permitted by basic requirements of American lumber standards for structural material (*28*).

COMPRESSIVE STRENGTH (ENDWISE)

Western larch ranks high among our native softwoods in the compressive strength (endwise) of its clear wood. Compressive strength endwise is a measure of the load-carrying capacity as a post or short column; that is, one whose length does not exceed 11 times its least dimension. The compressive strength of western larch averages lower than that of longleaf pine and about the same as that of Douglas fir (coast type) and loblolly pine, and higher than that of

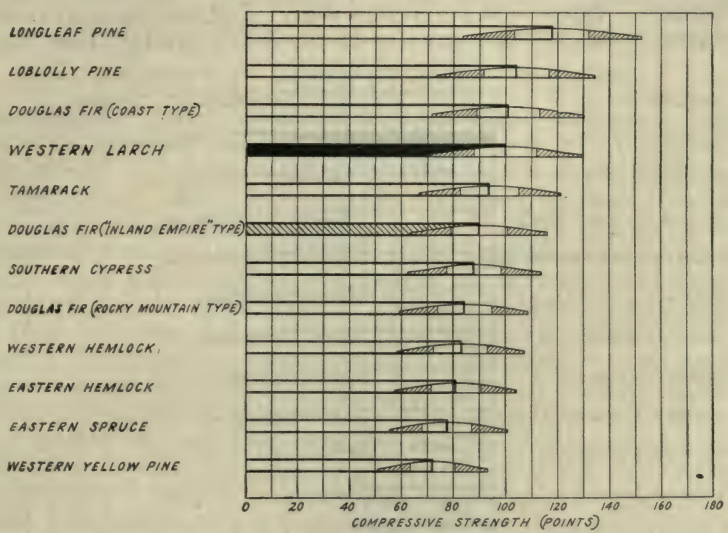


FIGURE 12.—Average and range in compressive strength (endwise) of clear wood of western larch as compared with that of other species of wood. The comparison shown here is for clear lumber. The effect of defects, difference in dressed dimensions, or moisture content, may equalize or reverse the relative values as charted. Western larch taken as 100 points. Average is shown by the end of the horizontal bar and range by the curve. One-half of all material of a species of wood will fall within the range shown by the blank space between crosshatched areas; 40 per cent in range shown by the crosshatching, 20 per cent above the average and 20 per cent below the average; while 10 per cent, 5 per cent above and 5 per cent below, will fall outside the range shown by the curve

southern cypress, the hemlocks, or the spruces. Douglas fir ("Inland Empire" type) averages about 13 per cent lower than western larch, and larch-fir mixture therefore has a lower compressive strength.

Compressive strength (endwise) is one of the most important properties required in mine props, porch columns, and posts that support girders of bins or buildings. In columns whose length is in excess of 11 times the least dimension, compressive strength (endwise) becomes less important and stiffness more important. A comparison of compressive strength (endwise) of western larch with other species is made in Table 4 and Figure 12. The comparison is directly applicable to small, clear pieces used as posts. A comparison of large-sized structural posts containing defects is best made on the basis of the working stresses given on page 58.

HARDNESS

Western larch does not mar, dent, or scratch readily. It is a hard softwood. Of our important commercial softwoods, only the southern yellow pines are harder than western larch. Douglas fir (all types) is softer, and the soft pines have only about half the hardness of western larch. (Fig. 13.) Western larch is, however, not nearly so hard as the denser hardwoods, such as the oaks, beeches, maples, and yellow birch. The larch-fir mixture of the common grades will average lower in hardness than western larch, for Douglas fir ("Inland Empire" type) is 9 per cent softer. The average hardness of the mixture will not vary greatly in the select grades from that of

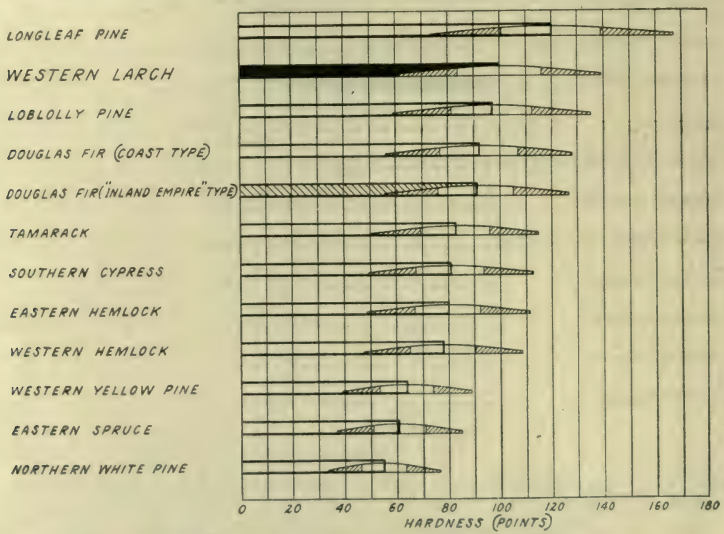


FIGURE 13.—Average and range in hardness of clear wood of western larch as compared with that of other species of wood. Comparison is applicable to lumber of all grades which contain only sound wood. Western larch taken as 100 points. Average is shown by the end of the horizontal bar and range by the curve. One-half of all the material of a species of wood will fall within the range shown by the blank space between the crosshatched areas; 40 per cent in the range shown by the crosshatching, 20 per cent above the average, and 20 per cent below the average; while 10 per cent, 5 per cent above and 5 per cent below, will fall outside the range shown by the curve

western larch. The small difference in the average hardness of the larch-fir mixture and western larch is not, however, a true measure of the resistance of the two to wear. Even a small percentage of the softer Douglas fir in a larch-fir mixture results in uneven wear. Western larch by itself is therefore preferable to a larch-fir mixture for surfaces that are to be subjected to heavy wear.

There is a pronounced difference in the hardness of the summer wood and spring wood of western larch. The summer wood is the dark portion of the annual-growth layer and is much denser, heavier, and harder than the lighter-colored spring wood. Western larch has very narrow but distinct layers of hard and soft wood. The alternate bands of hard and soft wood in the southern pines and in that type of Douglas fir known commercially as red fir are much wider than in western larch. The wood of the white pines is more uniform in hard-

ness than western larch in that they have no pronounced layers of hard and soft wood. Variations of hardness within the annual-growth rings should be considered as well as the average numerical hardness in making comparisons. Alternate bands of hard and soft wood tend to cause uneven wear and to deflect nails. In this respect, western larch is between Douglas fir and the hemlocks.

The hardness of western larch, other things being equal, makes it more resistant to wearing, crushing, or mashing than the softer softwoods. On the other hand, its hardness makes it more difficult to cut, shape, and nail, but makes it finish smoother and polish better than the softer softwoods.

CAPACITY TO WITHSTAND SHOCKS (TOUGHNESS)

Toughness or shock resistance is not the most important property in most of the uses into which western larch goes. Where very tough woods are required the heavier hardwoods, such as the hickories, ashes, and oaks, generally are used because they are so much higher in shock resistance than the best of the softwoods as to practically eliminate the latter. In a number of uses into which western larch goes, toughness is desired along with other more important properties. For example, strength in bending and compression (endwise) are the most important properties required in mine timbers. Toughness is desired because, other things being equal, the tougher the wood the more warning it gives of failure. Likewise, toughness is a desired property in other structural material. It is also important in such uses as ladder rails, wagon tongues, and automobile-body parts, for which softwood species are largely supplied.

Western larch has the same average toughness as Douglas fir (coast type). It is not so tough as southern yellow pine or tamarack but is tougher than southern cypress, eastern spruce, or Douglas fir ("Inland Empire" type). The lower toughness of the Douglas fir ("Inland Empire" type) results in the average toughness of the clear wood in the common grades of the larch-fir mixture being less than that of western larch. Detailed comparisons of the average and range of toughness of western larch with other softwoods are made in Figure 14.

STIFFNESS

Western larch is a stiff wood. It bends or deflects less under loads than tamarack, southern cypress, the hemlocks, or the spruces. It is not, however, so stiff as Douglas fir of either the "Inland Empire" or coast types, nor is it so stiff as the southern yellow pines. The difference in stiffness between western larch and the Douglas fir of the "Inland Empire" type is so small that the stiffness of the larch-fir mixture will not differ materially from that of western larch. The average and range of stiffness in clear wood of western larch are compared with that of other species in Figure 15. The comparisons hold almost as well for lumber as they do for clear wood, for defects have little influence upon the stiffness. The comparisons are, therefore, applicable to all grades.

Stiffness is an important requirement for many uses. It is the most important requirement in joists and studding for dwellings. Stiffness largely determines the load-carrying capacity of long col-

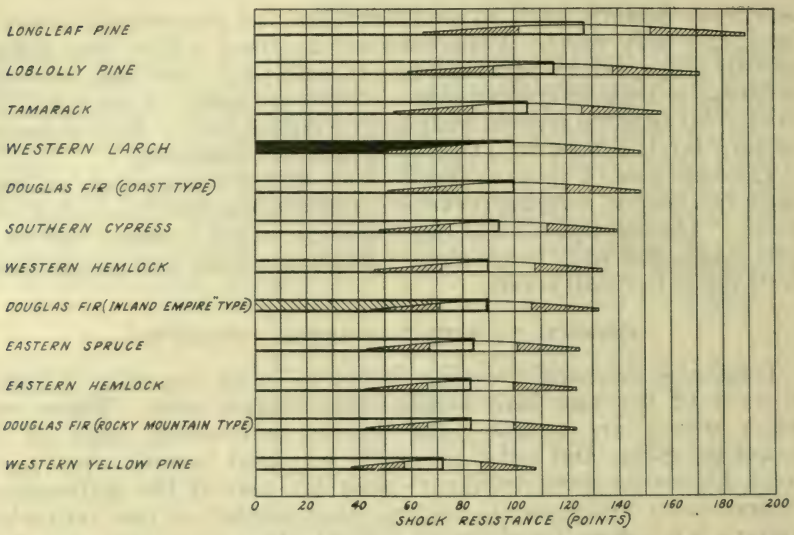


FIGURE 14.—Average and range in shock resistance of clear wood of western larch as compared with that of other species of wood. The comparison shown is for clear lumber. Western larch taken as 100 points. Average is shown by the end of the horizontal bar and range by the curve. One-half of all material of a species of wood will fall within the range shown by the blank space between crosshatched areas; 40 per cent in the range shown by the crosshatching, 20 per cent above the average and 20 per cent below the average; while 10 per cent, 5 per cent above and 5 per cent below, will fall outside the range shown by the curve

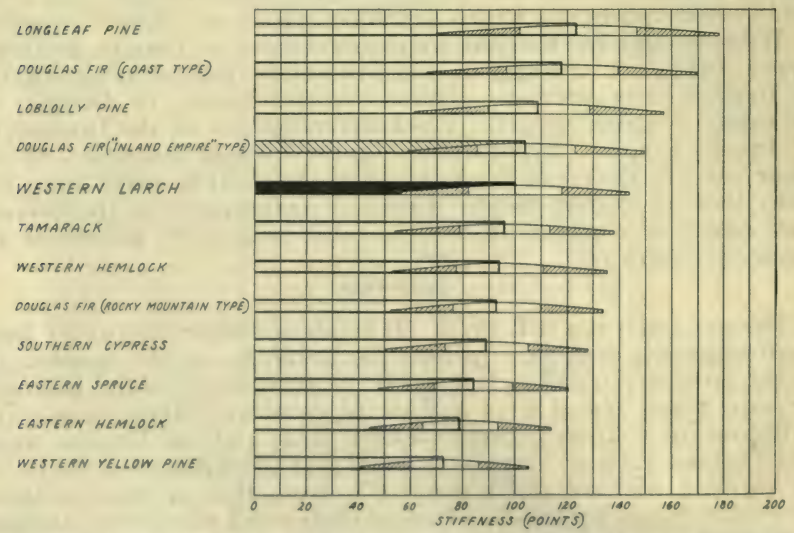


FIGURE 15.—Average and range in stiffness of clear wood of western larch as compared with that of other species. The comparison is based on clear wood but is applicable to lumber almost as well, provided the dressed size and moisture content are comparable since defects have little or no influence on stiffness. Western larch taken as 100 points. Average is shown by the end of the horizontal bar and range by the curve. One-half of all material of a species of wood will fall within the range shown by the blank space between crosshatched areas; 40 per cent in the range shown by the crosshatching, 20 per cent above the average and 20 per cent below the average; while 10 per cent, 5 per cent above and 5 per cent below, will fall outside the range shown by the curve

umns; that is, columns which fail by bending rather than by crushing. Side rails of ladders and footboards of bleachers are examples of other uses in which stiffness is an important requirement.

SEASONING

The satisfactory use of western larch is predicated upon proper seasoning of the wood. No single factor has operated more to discredit the real merits of western larch than has poor and inadequate seasoning.

Western larch is free from such serious drying difficulties as staining, collapse, or honeycombing. The comparatively slow rate at which the species dries and the tendency of material 10 inches and wider to cup, check, and split are the principal difficulties in drying western larch. The slow drying rate of the wood often results in western larch being marketed before it is thoroughly dried. The tendency of wide widths to check or split during air seasoning has resulted in manufacturers cutting three-fourths of the select grades into widths 4 inches and under, and about three-fourths of the common grades into thickness 2 inches and over. About one-half of the common grades are 6 inches or less in width, and practically none are wider than 12 inches. Such cutting practice has reduced trouble from cupping, checking, and splitting, but the real solution is to be found in proper kiln drying.

All sizes and grades of western larch can be satisfactorily kiln-dried. Boards 1 inch thick and 10 to 23 inches in width, green from the saw, were kiln-dried at the Forest Products Laboratory to a moisture content of 6 per cent in seven days with the drying schedule shown in Table 5. Higher kiln temperatures than those in Table 5 will shorten the drying time even more. Such increased temperatures, however, require greater care if excessive casehardening is to be prevented. Schedules for kiln-drying western larch in thicknesses ranging from 1 to 3 inches are available in publications of the Forest Products Laboratory (*25*).

TABLE 5.—*Experimental kiln schedule for drying inch western larch*

Time in kiln	Relative humidity	Temperature of air	Condition of lumber
Hours	*Per cent*	° *F.*	
0	100	165	Green; 60 per cent moisture.
3	80	165	Drying begins.
24	80	165	Free water evaporating.
48	80	165	Do.
72	80	165	Do.
92	80	165	Fiber-saturation point reached.
96	64	165	Drying and shrinkage.
120	47	165	Danger of casehardening and checking.
144	30	165	Danger of casehardening and checking.
168	30	165	Take out; 6 per cent moisture.

The best results can be obtained by kiln-drying western larch and Douglas fir in separate charges since western larch requires a longer schedule than Douglas fir in the select larch-fir grades. Separate drying, moreover, results in increased kiln output because of the faster drying of Douglas fir. Drying in separate charges is also

accomplished with less degrade because each species can be treated according to its drying requirements.

All western larch products intended for use where they must stay in place well should be kiln-dried to insure satisfactory service. The relatively large shrinkage of the wood makes it necessary to dry as near as practical to the moisture condition the wood will have in use. Interior finish in heated buildings in the North Central States, for example, will average about 7 per cent moisture content or lower. In unheated buildings interior finish will seldom average above 12 per cent. An average moisture content of 8 to 10 per cent is therefore required to reduce shrinkage to a minimum. Such low moisture-content values can not ordinarily be obtained in the "Inland Empire" by air seasoning.

About one-fourth of the western larch lumber produced is now kiln-dried. Within the locality that produces the bulk of the western larch lumber dry kilns are now the exception rather than the rule. Among the manufacturers that are equipped to kiln-dry the bulk of their daily cut, four produce practically 15 per cent of the total cut of western larch lumber. There is now, however, a very decided tendency within the "Inland Empire" to increase kiln capacity.

Western larch requires a much longer time to thoroughly air season than most softwoods. (Fig. 16.) Moisture determinations made on stock after 34 months' air seasoning in the "Inland Empire" showed values too high to be satisfactory for wood going into interior and dry locations. The moisture content of several hundred samples selected at random from winter shipments of western larch that had been in the yards 12 to 34 months had approximately one-third more moisture than the average of several thousand specimens similarly selected from 10 of the leading softwood species. Similar determinations on summer shipments showed the average moisture content of western larch decidedly higher than that of the other softwoods studied. Time in the seasoning pile can not, therefore, be relied upon by either producer or consumer for a satisfactory indication of the adequacy of seasoning.

The slow drying characteristics of western larch and the tendency of wide material to cup, check, and split present a perplexing problem in air seasoning. Checking, splitting, and warping are due to uneven shrinkage, and all may be reduced by methods of piling. Shading the ends of the stock will decrease the end checking and splitting. Warping can be reduced by piling methods that hold stock firmly in place and in alignment during drying. Surface checking can also be prevented by slowing down the drying rate. The slow drying characteristics of the western larch, however, make it problematical whether methods of piling to reduce degrade, which slow up drying, are commercially feasible. Where air drying must of necessity be practiced the moisture content should be frequently observed to be sure that the material is dry enough for use, and the seasoning should be studied to determine the piling methods that will give a satisfactory drying rate and still prevent excessive degrade.

The benefits from good seasoning are operating to improve the seasoning of western larch. The advantage of reduced shipping weights, especially with a wood as heavy as western larch, and the

advantages of decreasing degrade are evident and appeal directly to manufacturers. To these the consumer can add another indirect but more powerful appeal by an insistent demand for thoroughly seasoned wood. The consumer should make this demand to protect himself from unsatisfactory service from wood otherwise admirably adapted to his use. The improved seasoning which will result from such a demand will benefit the consumer, the producer, and the species.

FIGURE 16.—Air seasoning western larch in the "Inland Empire." About half the output of this mill is larch-fir

SHRINKAGE

Western larch shrinks more in drying from a green to an oven-dry condition than do any of the principal softwoods but less than many of the heavier, commercially important hardwoods. The average shrinkage of tamarack, the southern yellow pines, and eastern spruce is only slightly less than that of western larch. The difference in shrinkage between the foregoing species and western larch is not important for most practical purposes. There is a significant difference, however, between the shrinkage of western larch and Douglas fir (all types), southern cypress, the hemlocks, and the soft pines.

The larch-fir mixture shrinks less than western larch because the shrinkage of Douglas fir ("Inland Empire" type) is only 87 per cent of that of western larch. In the common grades the shrinkage of larch-fir will average about 93 per cent of that of western larch; in the select grades about 98 per cent since 90 per cent of the selects are western larch.

A comparison of the average and range of shrinkage of western larch with that of several other softwoods is shown in Figure 17. The comparison is based on the total shrinkage from a green to an oven-dry condition measured on specimens 1 inch thick, 4 inches wide, and 1 inch along the grain, which is a standard size used with all species in order to obtain comparable values. The comparatively large shrinkage of western larch is not primarily the cause of trouble resulting from changes in dimensions because several species with higher shrinkage than larch are used for exacting purposes with satisfactory results. Where change in dimension is of sufficient size to cause trouble it is usually the result of inadequate seasoning or

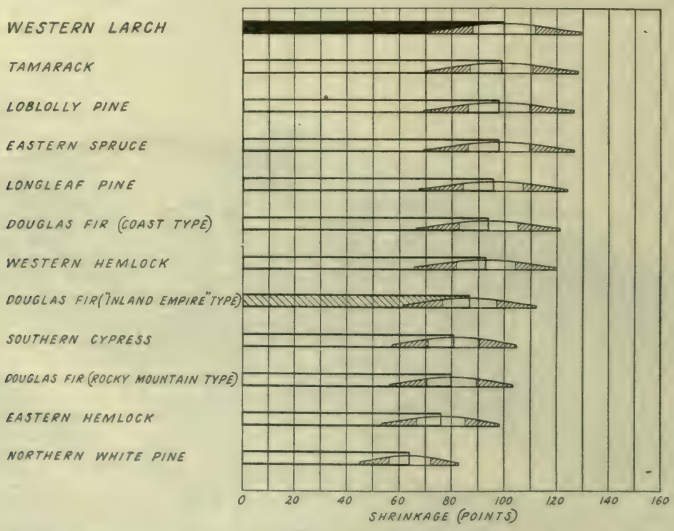


FIGURE 17.—Average and range in the total shrinkage from a green to an oven-dry condition of small, clear pieces of western larch as compared with that of other species of wood. Western larch taken as 100 points. Average is shown by the end of the horizontal bar and range by the curve. One-half of all material of a species of wood will fall within the range shown by blank space between crosshatched areas; 40 per cent in the range shown by the crosshatching, 20 per cent above the average and 20 per cent below the average; while 10 per cent, 5 per cent above and 5 per cent below, will fall outside the range shown by the curve

of storage conditions. When the wood dries in place the changes in dimension are, of course, relatively large and may result in unsatisfactory service. Such changes cause the shrinkage of western larch to appear larger as compared to other woods than it is. On the other hand, when the wood is used dry the slowness with which it picks up moisture reduces the tendency to change dimension and makes the relative shrinkage appear smaller than it is. The shrinkage of western larch, although relatively high, does not prevent the use of western larch for flooring, interior trim, and other purposes where only small changes in dimension are permissible.

Under most conditions differences in the shrinkage of western larch and other species are not so important as the moisture condition of the wood at time of use. For example, the shrinkage of northern white pine is about two-thirds that of western larch, but western larch shrinks over twice as much in drying from 18 to 6 per

cent as it does in drying from 12 to 6 per cent moisture. Shrinkage troubles with western larch, as with other species of wood, can be largely controlled by proper seasoning, but it follows that proper seasoning is more important with high-shrinkage woods than with small-shrinkage woods.

The average shrinkage to be expected in western larch lumber between any given moisture conditions can be obtained from Figure 18. For example, to determine the average change in dimension of 1 by 4 inch, edge-grained, western larch flooring between 6 and 12 per cent moisture, which are the approximate winter and summer moisture-equilibrium conditions of flooring in heated buildings in New England and the Lake States, a line through 6 per cent moisture meets the edge grain or radial shrinkage curve at 3 per cent. A similar line through 12 per cent meets the edge-grain curve at 2 per cent. The difference between the two values is 1 per cent. One per cent of 3⅝ inches (actual width of nominal 4-inch flooring) is about one-twenty-eighth of an inch. A similar determination for flat-grained flooring shows a change in dimension of about one-fifteenth of an inch. The curves of Figure 18 are based on measurements made on short sections of boards selected from a commercial run of lumber (*19*). The shrinkage in the width of flat-sawn western larch lumber from a green to oven-dry condition is about 7 per cent of the original green width. The shrinkage in width of edge, or vertical-grained, western larch lumber is 4 per cent of the green width. Most of the shrinkage in western larch takes place below 28 per cent moisture. The small amount of shrinkage (about one-half of 1 per cent) that takes place above 28 per cent moisture content is of little practical importance. Some shrinkage does occur in lumber at high moisture-content values (40 per cent); it is very small, however, only a small fraction of 1 per cent, and is due to the drying of the outside fibers while the interior of the piece is still in the green condition.

ABILITY TO STAY IN PLACE

Ability to stay in place is a desirable property in all lumber. It depends on a combination of the shrinkages and the tendency of the wood to warp. Shrinkage is a measure of the change in dimension. Warping is the tendency of wood to change in shape. From the log to the finished product warping and change in dimension are a source of loss and trouble.

In so far as shrinkage is concerned, previous comparisons have shown that western larch changes in dimension more than most of the softwoods, but not so much as the denser or heavier hardwoods. The change in dimension of thoroughly seasoned western larch is not sufficient to cause complaint in such uses as interior trim and finished flooring, but would be objectionable in such uses as patterns.

No numerical evaluation can be made of warping tendencies, either for comparison of species or for determination of amounts. The tendency of western larch to warp, however, can be judged to some extent by its past behavior and general reputation. The species has given some trouble in seasoning from cupping, especially in boards of widths in excess of 10 inches (p. 27). Because of its straight grain, little trouble has been experienced with western larch from

warping of the twisting type. Once properly seasoned, western larch stays in place well. The dry wood has a reputation among retailers of "yarding" well; that is, it is easy to pile, stays straight in the pile, and the degrade in storage is small. Its reputation among users for staying in place is good with those who use it for framing, subfloors, sheathing, and other rough usages, indicating that the wood will not work out of place sufficiently to be objectionable in such uses.

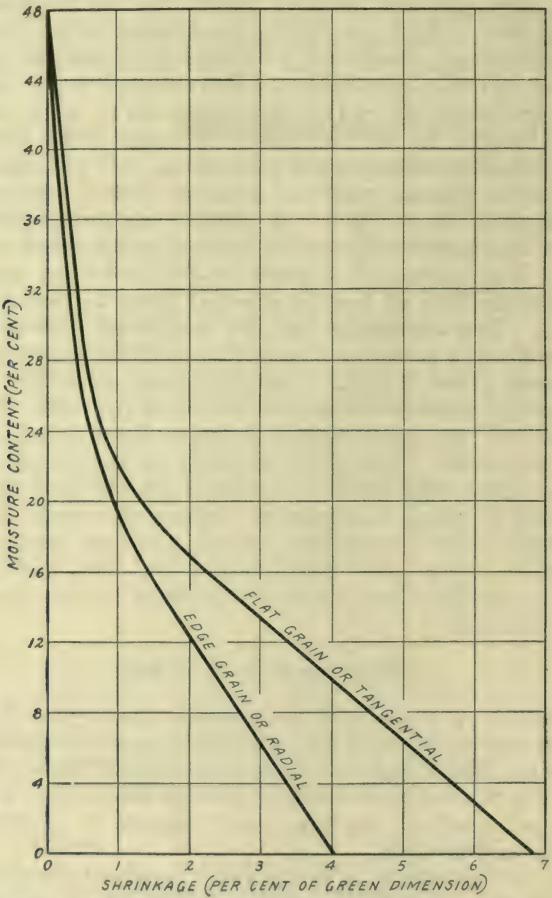


FIGURE 18.—Shrinkage of flat and edge grained western larch. Based on tests of heartwood specimens in the form of 1-inch boards cut from commercial run of lumber. An estimate can be made with the aid of this chart of the amount of change in dimension that will take place with changes in the moisture content of the wood

EASE OF MACHINING AND WORKING

Smooth surfaces are easy to obtain with western larch, but the effort or power required is relatively high for a softwood. The smoothness of the surface is probably due to the hardness, density, and uniform narrow annual-growth ring of wood. The hardness and the alternate bands of hard and soft wood are responsible for

the amount of power and effort required to work the wood. The smoothness of the dressed surfaces is quite noticeable in the piling or handling of the lumber. The boards slide on one another more readily than boards of the other western softwoods. A tendency of quarter-sawed stock to sliver on edge or for edges to feather is also noticeable in handling. The alternate bands of hard and soft wood are largely responsible for this tendency. In occasional shipments the feathering of edges of quarter-sawed stock has been sufficient to be objectionable. When feathering is sufficiently pronounced to be objectionable it is probably the result of working the wood while it is still wet. Dull knives or poor machining may also be responsible for feathering.

In ease of working and machining, western larch is between Douglas fir (all types) and longleaf pine. The Douglas fir (all types) is softer and easier to cut, saw, and shape but does not dress so smoothly. Longleaf pine and shortleaf pine are harder and require more effort to cut, saw, and shape, while loblolly pine requires about the same. The narrow and uniform width of growth rings of western larch have a favorable influence on its workability, reducing the adverse influence of alternate bands of hard and soft wood. Its hardness increases the tendency of knots to break or crack in planing. This is evident in the lower grades, where broken knots are more prevalent than in the Douglas fir ("Inland Empire" type). On the other hand, the clear wood of western larch dresses to a smoother surface and breaks back less in crosscutting than Douglas fir, that is, the sawed surfaces are cleaner cut and the edges of ends less slivery. The hemlocks, true firs, and spruces are all easier to cut than western larch, but the edges and surfaces are not so good.

The moisture content has a pronounced influence on the ease with which a wood works. Wet or green wood cuts and saws easier than dry wood but does not finish to so smooth a surface. Wood has a tendency to fuzz when planed before it is thoroughly dry. The grain also may rise or loosen. The tendency to fuzz, however, is not so pronounced in western larch as in softer woods, but the tendency of the grain to rise or loosen is greater than in more uniformly textured woods.

When saws or planes stick in working western larch the sticking is caused by galactan rather than by resin. Galactan is a water-soluble extractive, which occasionally exudes on the surface of western larch. Galactan has a less pronounced effect on workability than the resin in such woods as Douglas fir (all types) and the southern yellow pines. Water is used to eliminate trouble from galactan just as kerosene is used with resinous woods. Galactan seldom causes trouble at the planer but does at times gum the saws. Trouble from this source occurs principally with green wood.

NAIL-HOLDING CAPACITY

One of the desirable properties of western larch is its high nail-holding power. Not only does the wood hold nails well when they are first driven into it, but it retains its nail-holding power well under varying moisture conditions. All woods lose heavily in nail-holding

power when the nails are driven into wet wood that later dries. Some species retain only about 10 per cent of their original nail-holding power under such severe conditions. It is, therefore, poor practice to nail into wet western larch or any species when the wood will later dry in use.

Western larch ranks near the top of the softwood group in nail-holding power (*17*). (Fig. 19.) It is between longleaf and loblolly pine in nail-holding power and is higher than Douglas fir (coast type), the hemlocks, soft pines, or the spruces. It is higher, for example, than red gum, a hardwood used extensively in automobile bodies, where nail and screw holding properties are important requirements. There are no data available on the nail-holding power of the "Inland Empire" type of Douglas fir; therefore, a comparison can not be made between western larch and larch-fir mixture. Judg-

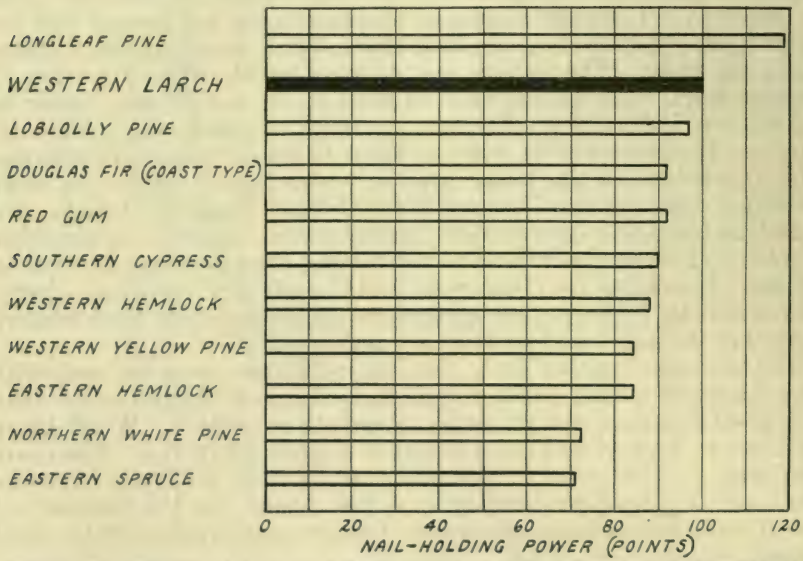


FIGURE 19.—Results of tests on holding power of nails driven into and pulled at once from dry, clear wood of western larch as compared with that of other species of wood. Western larch is taken as 100 points

ing from the specific gravity of the two species, however, it appears probable that the nail-holding power of Douglas fir ("Inland Empire" type) is between 10 and 15 per cent lower than that of western larch.

The foregoing comparisons and those shown in Figure 19 are based on pulling tests of 7-penny cement-coated nails driven into flat-grained and edge-grained faces. Other tests indicate that the comparisons will hold for other sizes and types of nails.

Data on only a small number of species are available for comparison with western larch for retention of nail-holding power as the wood dries out. The comparison of retention of nail-holding power is complicated by the influence of time. Tests made on the resistance to withdrawal of nails driven into green wood and pulled after the wood had thoroughly air-dried showed western larch retained its nail-holding power well.

The high nail-holding power and high retention of holding power in drying of western larch are a desirable combination of properties, especially in such uses as in boxes and crates, which change from damp to heated storage, in freight cars, which are subjected to a wide range of climatic conditions, and in automobile bodies, which are alternated between heated garages and direct exposure to the elements.

SPLITTING

The prevention of splitting in seasoning, nailing, and handling western larch requires special attention. In air seasoning, splitting is partly controlled by manufacturing narrow widths in preference to wide ones; in kiln-drying, by the use of special drying schedules

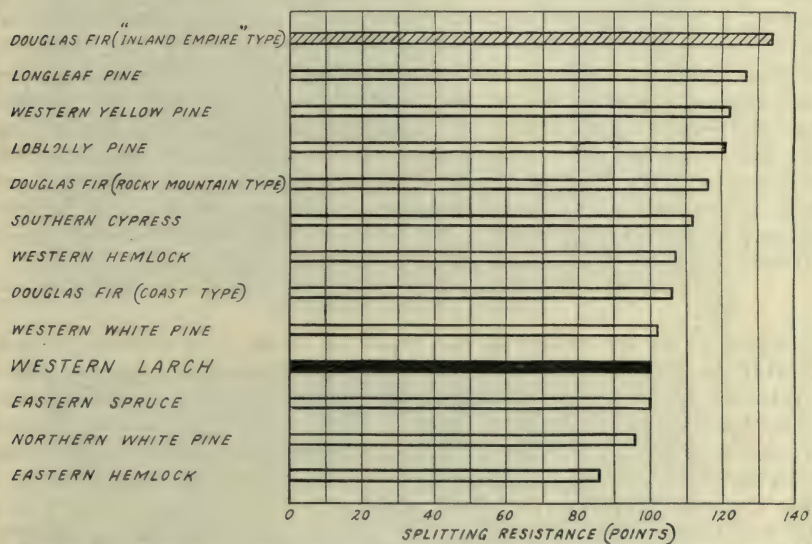


FIGURE 20.—Results of tests on the inherent splitting resistance of clear wood of western larch as compared with that of other species. Western larch taken as 100 points. Splitting resistance is a measure of the resistance to splitting from action of wedges and bolts but is not a direct measure of the tendency to split in nailing because hardness, width of annual rings, and texture also influence the splitting in nailing

(p. 27); and in nailing, by the use of blunt or smaller nails than are used with lighter, softer, and more uniform textured woods. The tendency of western larch to split in seasoning and handling is due to the low inherent resistance of the wood to splitting combined with its comparatively high shrinkage. The high hardness of the wood combined with its low inherent splitting resistance is responsible for the tendency of western larch to split in nailing.

Western larch is easy to split with wedge or ax. (Fig. 20.) The inherent resistance to splitting of western larch is about the same as that of spruce and the white pines, and is lower than that of Douglas fir (all types) and southern yellow pine. Douglas fir ("Inland Empire" type) has a high inherent resistance to splitting; consequently, the average splitting resistance of the larch-fir mixture in the common grades is about the same as that of the southern yellow pines and is higher than that of Douglas fir (coast type). In the select grades, where the percentage of Douglas fir ("Inland Em-

pire" type) is small, the average splitting resistance is about the same as that of Douglas fir (coast type). The foregoing comparisons are based on wood free from shakes, season checks, or other defects.

Western larch does not split in nailing so much as would be expected from a study of its hardness and inherent splitting resistance. This was shown by a recent study at the Forest Products Laboratory in which a large number of nails were driven into a small number of specimens selected to represent the range in specific gravity and ring growth to be found in western larch and five other softwoods. The percentage of splits in western larch was slightly less than in Douglas fir (coast type) or in western hemlock, but slightly greater than in southern yellow pine, southern cypress, or white fir, and several times greater than that in northern white pine. Wide-ringed material split more under the nails than narrow-ringed material, which accounted to some extent for the favorable showing made by western larch. Edge-grained material split less than flat-grained material or material in which the grain was intermediate between flat and edge. The heavy specimens of a species split more than the light ones of the same species. These are factors which should be considered in comparing the splitting resistance of western larch with other species. The comparisons, however, should all be considered as tentative until a more comprehensive study can be made of the tendency of woods to split in nailing.

GLUING CHARACTERISTICS

Glued joints as strong as the wood in shear and tension perpendicular to grain can readily be made with western larch. Such joints can be produced with both flat-grained and edge-grained material by the use of the schedules of Table 6 with vegetable, animal, or casein glues. The characteristic failures of western larch glued with vegetable glue are shown in Plate 3. The photograph, which is also typical of failures with animal and casein glues, shows how the wood tore apart while the glue held, indicating that satisfactory joints were obtained.

TABLE 6.—*Gluing schedules for western larch*

Kind of glue	Proportion of glue to water by weight [1]	Glue spread	Temperature of the wood	Pressure	Closed assembly time [2]
		Lbs. per 1,000 sq. ft. [3]	°*F.*	*Lbs. per sq. in.*	*Minutes*
Animal [4]	1:2¼	65–70	70	125–175	⅓– 1
	1:2¼	70–75	80	125–175	2 – 5
	1:2¼	75–80	90	125–175	7 –18
	1:2¾	75–80	90	125–175	10 –20
Casein [5]	1:1⅓	70–75	70–90	150–200	0 –12
	1:2	75–80	70–90	150–200	5 –20
Vegetable [5]	1:2¼	60–70	70–90	100–150	0 –20
	1:2¼	70–80	70–90	100–150	1 –25

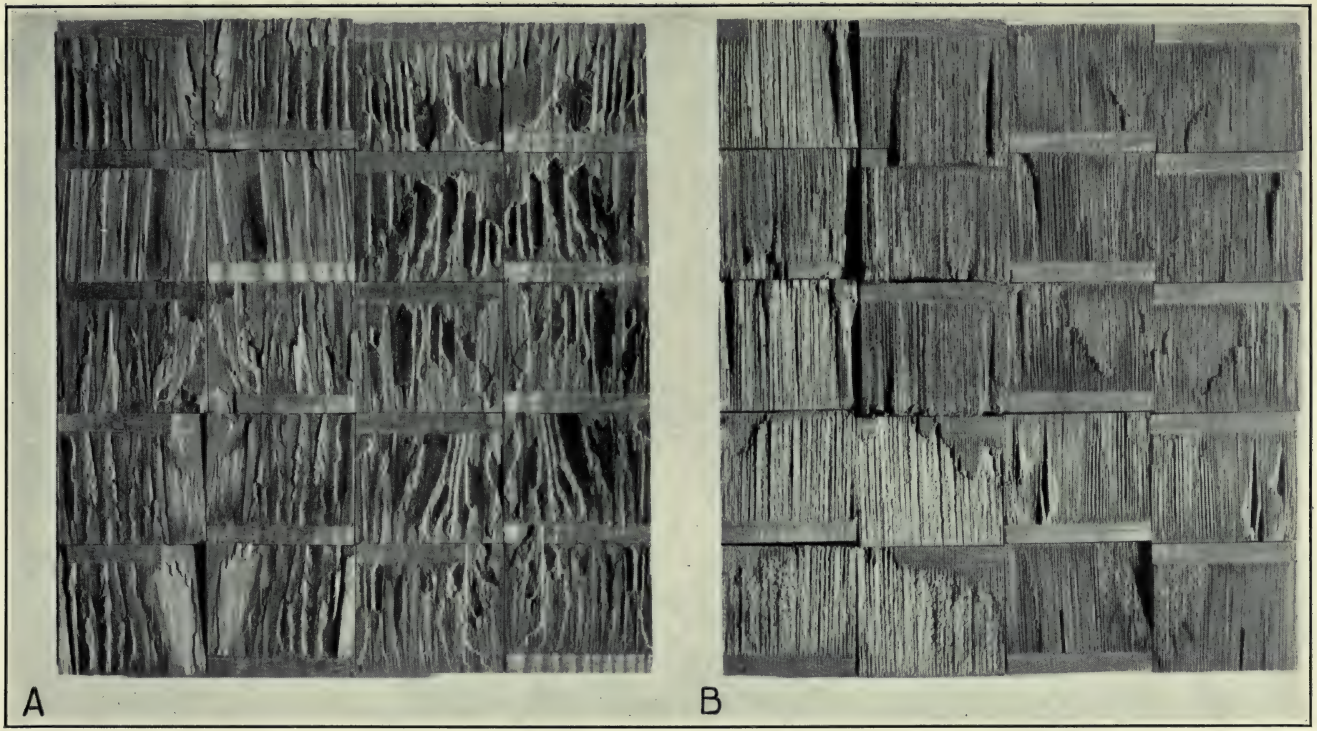
[1] The recommended proportions of glue and water are suitable for both lumber and veneer gluing, but ordinarily it is better to use a thicker glue mixture with lumber than with veneer.

[2] Wood pieces laid together as soon as spread with glue.

[3] Weight of wet glue mixture.

[4] An animal glue equivalent to about a No. 12 in the National Association of Glue Manufacturers' grades. Other grades may be used if suitable adjustments in the proportions of glue and water are made.

[5] Some commercial glues require more or less water than given here in order to obtain the same consistency of mixture.



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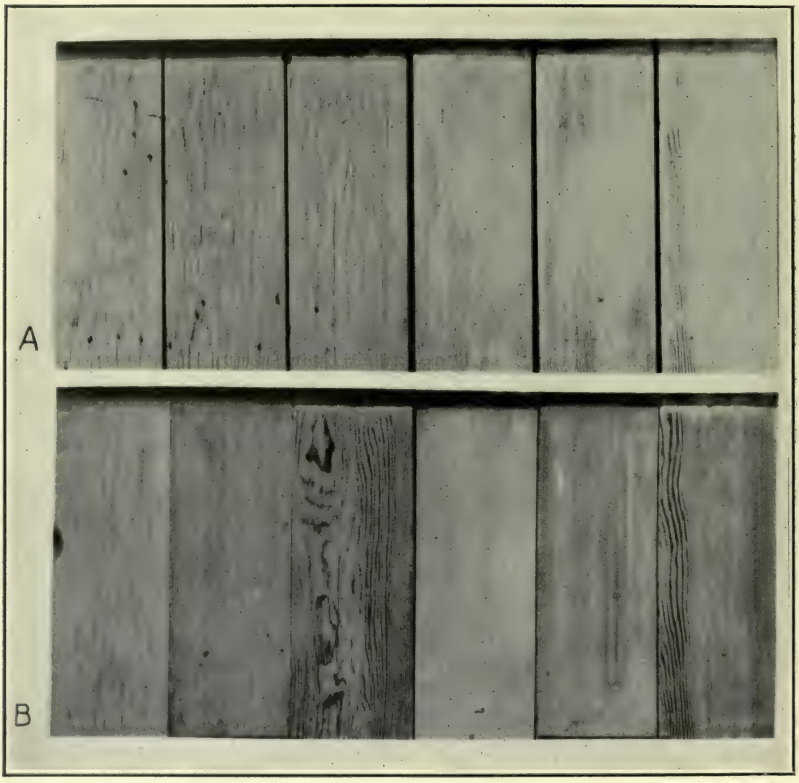
Glued joints as strong as the wood in shear and tension across the grain can readily be made with western larch. The illustration shows how the wood when tested to failure tore apart while the glue held. The failures are typical of those obtained with vegetable, animal, and casein glues. A, Flat-grained western larch; B, edge-grained western larch



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A, Edge and flat grained painted panels of western larch after two years exposure at Madison, Wis., facing south and inclined 45° to the vertical. This is equivalent to about three years exposure in a vertical position facing south and perhaps four or five years facing north. Wood checking is evident in the flat grain on the left, and the paint is flaking from the summer-wood bands. Repainting should not be delayed. (Holes shown in panels on left are the result of gunfire and are not defects); B, same specimens as shown in A after four and one-half years exposure. The first and fourth panels from the left received one coat and the second and fifth panels two coats at the end of three years exposure. Note difference in checking as a result of four and one-half years exposure in the third specimen which is flat grain and the sixth which is edge grain

The animal-glue schedules of Table 6 are recommended (*26*) for use with the sapwood of eastern red cedar, southern yellow pine, and western yellow pine, as well as western larch. More restrictive schedules are recommended for the heartwood of eastern red cedar, heartwood of southern cypress, and many of the hardwoods.

The average strength of glued joints made at the Forest Products Laboratory with western larch was high for a softwood. Joints made with vegetable or animal glue in accordance with the schedules of Table 6 averaged over 1,600 pounds per square inch; with casein glue, over 1,800 pounds per square inch. Under extremely adverse conditions, animal glue joints averaged over 1,200 pounds per square inch.

PAINTING AND FINISHING CHARACTERISTICS

Western larch exposed to the weather should be painted at relatively frequent intervals. In this respect western larch is classed with Douglas fir (coast type) and southern yellow pine. These three woods, largely because of their high density combined with their distinct alternate bands of hard and soft wood, do not hold paint so long as the lighter and more uniform textured softwoods. The paint on western larch fails by flaking from the summer-wood bands. (Pl. 4.) Repainting, however, is generally advisable before flaking takes place in order to protect the wood from checking and to prevent cupping. The white pines, cedars, southern cypress, and redwood hold paint the longest of any of the woods studied at the Forest Products Laboratory. The spruces, true firs, hemlocks, and western yellow pines were between this group and western larch.

The Forest Products Laboratory is studying the painting characteristics of 17 native softwoods, including western larch. The study has been in progress for seven years and is conducted on panels exposed on test fences at widely scattered points throughout the United States. The test panels include flat-grained and edge-grained material and both white-lead and lead-zinc paint are used. Details of the work and the conclusion drawn from the study are available at the laboratory (*6*).

The species comparisons just made are based on the behavior of paint on clear wood. A special study of knotty western larch showed that paint did not discolor around knots and that knots held paint well, there being no early flaking of paint from knots. (Pl. 5, A.) Shellac or other knot sealers are therefore unnecessary and should not be applied over the knots in western larch. The indications from this study are that paint on knotty western larch will maintain a better general appearance than on woods with high resin content.

Ordinarily western larch that is freely exposed to the weather should be repainted at intervals of about three years. The time, however, varies greatly with exposure, climatic conditions, with edge-grained and flat-grained material, and with quality and type of paint. If surfaces facing south are shaded by trees or buildings, repainting may not be needed oftener than once in four or five years. On the other hand, under adverse climatic conditions, where at times there is much sunshine, little rain, and periods of low humidity, it may be necessary to renew coating oftener than every three years.

Prepared paints containing a moderate proportion of zinc oxide can be used to better advantage on western larch than they can on

heavy softwoods that contain more resin, because resins seem to affect adversely the durability of paints containing zinc oxide.

Edge-grained material requires repainting less often than flat-grained material. (Pl. 4.) While this is true of practically all softwoods, the difference is much more pronounced in western larch than in lighter and more uniform textured woods. On an average the paint coatings lasted about half again as long on edge-grained larch as they did on flat grained in the tests at Madison, Wis. Again, the time varies widely with climate, location, and type and quality of paint. Where flat-grained boards are used, especially out of doors, they should be placed with the sapwood side rather than the heartwood side exposed to the weather. This will largely prevent the development of loose and raised grain.

The durability of paint on western larch can be increased at least one year by applying one coat of exterior aluminum paint (*7*) to bare wood before painting with ordinary house paint. Such a coating, consisting of one coat of aluminum primer and two coats of white or light-colored paint, costs about the same as a standard 3-coat job but lasts longer because flaking of the coating from the summer wood is retarded. When the added durability is considered, the cost of the coating with aluminum primer and two top coats of ordinary paint is usually less than the cost of a 2-coat paint job, even if skillfully applied. With paint of a dark color one coat over aluminum primer is sufficient.

The results of the painting study are not directly applicable to interior conditions. The painting of interior woodwork is primarily for appearance or sanitation rather than for protection of the wood. Normally, checking of wood or flaking of paints from summer-wood bands does not occur on interior trim. Repainting time for interior trim is therefore normally the result of the soiling of the paint by dust, soot, grease, or the like. The hazard from such causes varies with the use, as does also the amount of soiling or marring which can take place before repainting is necessary. Generally, lighter and more uniform-textured woods are preferred to western larch for smooth-paint and enamel finishes. Where western larch is used it is generally given a natural or stain finish, although it will take and hold paint and enamel finishes. (Fig. 21.)

Beautiful effects can be obtained on western larch with spirit stains or natural finishes. (Fig. 22.) On the other hand, fuming is not recommended for use on western larch, for fuming has little effect on the wood. Three-coat finishes consisting of one coat of penetrating stain, one coat of white shellac, and one coat of interior varnish were applied to western larch specimens, a number of commercial shades of oak stains being used. Brown and dark mahogany primers with one coat of interior varnish and no shellac were also tried. The wood took all stains well, and the figure of the flat-grained material was brought out in greater relief. Light, bright tones were obtained with natural finishes consisting of one coat of silex filler lightly sanded, plus one coat of interior varnish rubbed with very fine steel wool, plus a second coat of varnish which when dry was rubbed with pumice stone and rubbing oil. This finish may be waxed if desired.

Two other types of finishes which gave good results in tests at the Forest Products Laboratory and which are applicable to either the natural or stained wood are: (1) One coat of white shellac, rubbed with fine steel wool and finished with two coats of prepared wax; (2) one coat of shellac followed by two coats of interior varnish, each coat except the last being lightly rubbed with steel wool.

A very high polish can be obtained with finish (2) by rubbing the final varnish coat with pumice stone and oil and polishing with an agent composed of 2 parts of white shellac and 1 part raw linseed oil. Finish (2) may also be polished by rubbing with pumice stone and oil and polishing with prepared wax. These materials properly applied present a pleasing and durable finish.

FIGURE 21.—Mantel and built-in fixtures of western larch finished in white enamel

RESISTANCE TO DECAY, WEATHERING, AND INSECTS

The heartwood of western larch is moderately decay resistant. It is used satisfactorily without preservative treatment where the decay hazard is not high. Like other woods, however, the life of western larch is doubled or tripled by a good preservative treatment. Not only is the heartwood of western larch moderately decay resistant, but the decay resistance of heartwood is largely retained in the lumber because of the small amount of sapwood it contains. The sapwood of all species rots readily under conditions favorable to decay. The decay resistance of any lumber is, therefore, dependent not only on the resistance of the heartwood, but on the percentage of sapwood present. In judging the suitability of western larch lumber for uses requiring decay resistance, consideration should, therefore, be given to the fact that repairs and maintenance may be smaller with western larch lumber than with lumber of species with more decay-resistant heartwood but a higher percentage of sapwood. (Fig. 23.)

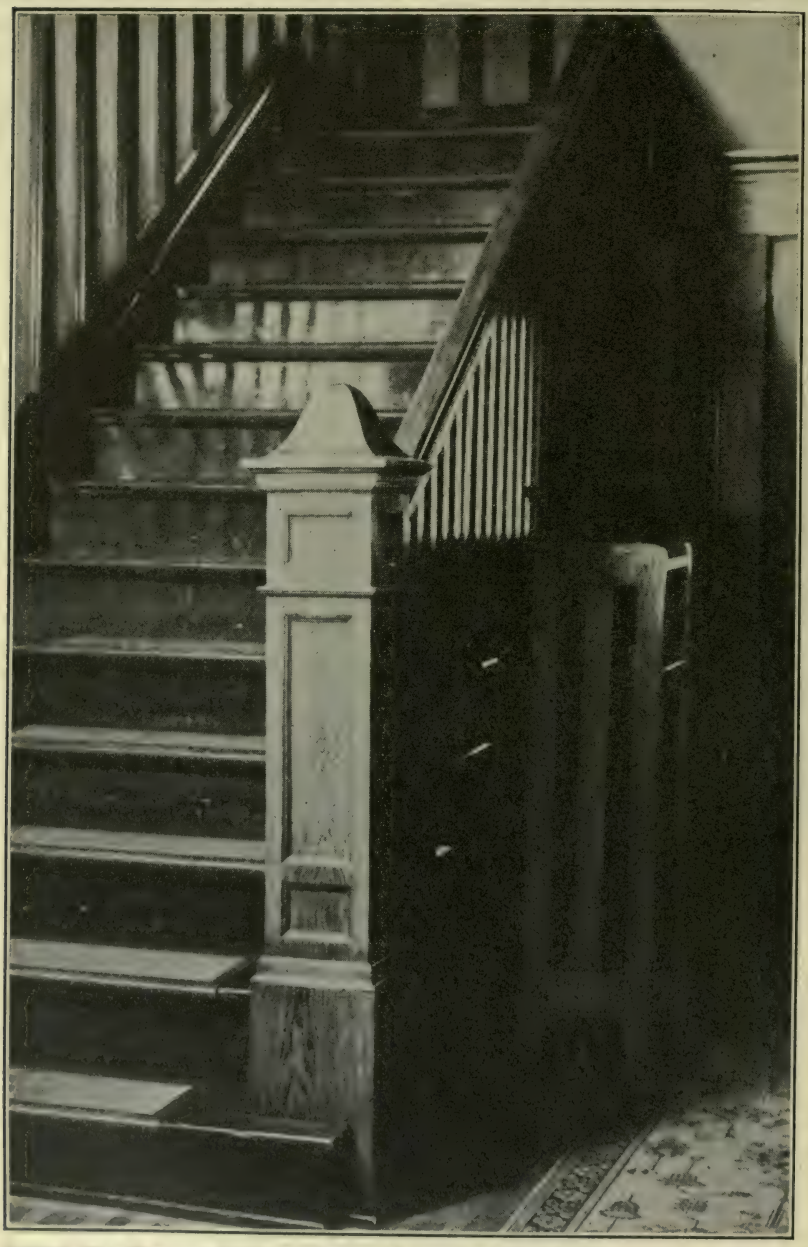

FIGURE 22.—Western larch stairway and panel strips showing effect obtainable with natural and stain finishes

Numerical comparisons of the decay resistance of western larch with other species are not satisfactory. Such comparisons based on service records can not be exact for removal for decay is always a matter of judgment. In addition, life in service varies widely with locality and use.

A general comparison based on service records where available, supplemented by general experience, indicates that the heartwood of western larch is very similar in decay resistance to that of Douglas fir (all types), southern yellow pine, and tamarack. Western larch is classed as lower in decay resistance than the heartwood of the

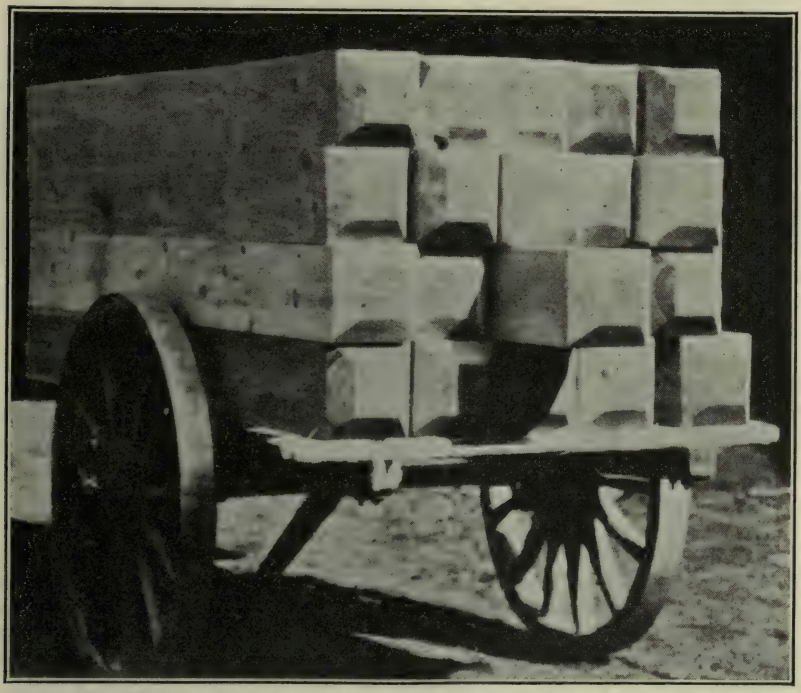

FIGURE 23.—Western larch highway guard-rail posts. The moderate decay resistance of the heartwood and the narrow sapwood ring of western larch are advantageous where posts are to be used untreated

cedars, chestnut, and southern cypress, but higher than the hemlocks and spruces. The average life to be expected of untreated western larch under conditions favorable to decay, as indicated by service records on untreated crossties in the "Inland Empire," was a little over seven years. Douglas fir ("Inland Empire" type) installed in the same track had practically the same average life. Western larch treated with zinc chloride had an average life of 14 years.

All woods weather when exposed to the elements. Weathering in western larch, especially if the wood is exposed before thoroughly seasoned, takes place in a comparatively short time. Unpainted western larch panels showed some checking three weeks after exposure. At the end of four years the weathering in the western larch panels was more pronounced than in Douglas fir (coast type) or southern yellow pine and considerably more pronounced than in

the cedars and southern cypress. The difference between species is much more pronounced in flat-grained than in edge-grained material. The weathering of western larch can be prevented by thoroughly seasoning the wood before exposing it to the weather and by protecting it with paint. The paint should be applied as soon after exposure as possible, and a good paint coating should be maintained.

All native species are susceptible to the attack of termites, or white ants, but some are more resistant than others. The prevention of damage from termites is best accomplished by preservative treatment and special care in construction (*22*), not by selection of resistant species.

REACTION TO PRESERVATIVE TREATMENT

Wood-preserving plants report that from a treating standpoint there are two types of western larch. One type treats very much like coast-type Douglas fir, the other like the Rocky Mountain type of Douglas fir. The western larch with treating characteristics like the Rocky Mountain type of Douglas fir is reported to come from higher altitudes and to have wider growth rings and to be more difficult to treat than the western larch from lower altitudes, which has the characteristic narrow growth rings of uniform width. Good penetration in crossties is obtained with the narrow-ringed type of western larch when the ties are incised.

Very little experimental work has been done on the preservative treatment of western larch. Most of the information available has been obtained from a study of the experiences of commercial treating plants with the species. Commercial plants are treating a large number of western larch crossties.

HEAT-INSULATION PROPERTIES

No tests are available on the heat conductivity of western larch. Tests made on other species indicate that the heat conductivity of wood is proportional to its specific gravity (*3*, *21*, *30*). Western larch would, therefore, be expected to conduct heat somewhat better than Douglas fir (coast type), but not quite so well as southern yellow pine.

Differences in the heat conductivity of species are, however, of small practical significance in most uses of lumber. The heating requirements of buildings are dependent more on tightness of construction and method and amount of insulation used than on the species (*20*). Western larch and other species all have high insulating properties as compared with most other structural materials.

PERMEABILITY BY LIQUIDS

Liquids penetrate western larch with difficulty. This fact is shown by the difficulty encountered in forcing preservatives into the wood. While the impermeability of the wood is a handicap to preservative treatment, it is a distinct asset in some uses, such as tight cooperage, silos, and tanks. The wood is very similar to Douglas fir (coast type) in this respect. Liquids penetrate western larch less readily than western yellow pine but more readily than Douglas fir ("Inland Empire" type).

TENDENCY TO IMPART ODOR OR FLAVOR

The wood of western larch is slightly resinous, falling between the spruces and Douglas fir in this respect. Western larch, however, is without distinctive odor or flavor. In so far as is known, western larch does not impart odor or flavor to food or liquids and normally can be used for boxes, barrels, and tanks without danger of contaminating the contents.

TENDENCY TO LEACH OR EXUDE EXTRACTIVES

Although western larch is slightly resinous, it has only a small tendency to exude resin. In this respect western larch is between the spruces and Douglas fir. Western larch does, however, exude a water-soluble gum known at galactan, which is sometimes mistaken for pitch. Galactan exudations are confined largely to material from butt logs; consequently, much of the material rich in galactan is left in the woods because the butt logs are often too heavy to float or are too shaky to be cut into profitable lumber.

The wood of western larch has no tannin or water-soluble material that will leach out and stain paint or plaster.

CHEMICAL PROPERTIES

The principal chemical difference between western larch and the other softwoods is in the nature of the extractives the wood contains. The basic chemical composition of the wood itself is very similar to that of other species of softwood. The wood is peculiar chemically in that it contains galactan, a water-soluble gum. Galactan can be hydrolyzed into galactose, and can be oxidized into mucic acid. Galactose, which is a sugar, has no commercial value at present. The very small amounts, a few pounds, now used by universities and chemical laboratories are obtained from milk sugar. Mucic acid obtained from galactan has been used commercially in place of tartaric and phosphoric acid in the manufacture of baking powder.

The galactan in western larch makes the wood suitable as raw material for the production of ethyl alcohol. Higher yields of ethyl alcohol are obtained with western larch than with other softwoods because both wood and galactan can be hydrolyzed to sugar that can be fermented for the production of alcohol. The species, however, has not been used commercially for this purpose, principally because practically all ethyl alcohol is obtained commercially from raw materials other than wood.

FIRE RESISTANCE

Western larch, like all other species, will ignite and burn at temperatures prevalent under fire conditions in structures. The difference in the ignition temperature of western larch and other species is small as compared to the difference in ignition point of untreated wood and wood which has received an effective fire-retardant treatment. Differences within species with reference to oil, density, and resin are as significant from a fire-resistance standpoint as differences between species. When fire resistance is required in untreated

wood it should be selected for high density and low oil and resin content. High fire resistance, however, is best obtained by giving the wood a fire-retardant treatment.

CHARACTERISTIC DEFECTS[8] OF WESTERN LARCH

Natural, seasoning, and machining defects are found in western larch as in all other woods. Natural defects are developed in the growing tree. Their occurrence can be controlled only by selection of trees and grading and selection of logs and lumber. They, therefore, show up in lumber as a permanent characteristic of the wood. Seasoning and machining defects, on the other hand, are developed in the lumber, not in the tree, and are therefore subject to control. Improved machinery, methods, and practices may change the size, character, or number of such defects and may even eliminate some of them. Although the frequency with which these seasoning and machining defects occur is, in some cases, influenced by the properties or characteristics of the wood, they can not be said to be truly characteristic of any species. In the following discussion such defects should only be considered as indicative of what may be expected under current practice.

The frequency with which the more important defects occur in western larch is shown in Table 7, which is based on a study of the defects in 14 of the principal commercial softwoods made at a number of representative mills. The occurrence of defects is shown separately for the select and common grades and for the mill run.

TABLE 7.—*Character and occurrence of defects in western larch*[1]

Defects[2]	Frequency of occurrence in—			Defects[2]	Frequency of occurrence in—		
	Select grades	Common grades	Log run		Select grades	Common grades	Log run
	Per cent	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*
Knots	60.1	96.3	82.4	Pitch	9.2	4.2	5.1
Check	54.5	69.4	63.6	Shake	2.7	7.7	5.8
Torn grain	19.4	19.8	19.6	Pitch streak	2.5	2.9	2.8
Split	8.8	24.8	18.6	Stain	1.9	1.7	1.8
Puncture	17.5	6.5	10.7	Chipped grain	3.3	.3	1.4
Pitch pocket	10.2	9.1	9.5	Decay	.5	3.5	2.8

[1] Based on 1,435 specimens 1 by 8 inches in size, studied by the Forest Products Laboratory.
[2] The defects are defined in American lumber standards (28).

NATURAL DEFECTS

KNOTS

Knots in western larch, as in other species, are the most numerous and most important of the defects. They are characteristically small, and most of them are encased. Knot holes and decayed and loose knots are fewer in western larch than in most softwoods, but knot clusters are more frequent. (Pl. 5, B.)

The knots in western larch averaged smaller in size than in any other important commercial softwood studied. The average size

[8] American lumber standards (28) defines and classifies defects. The discussion of characteristics in this bulletin is based on those standard definitions.

of knot in the mill run of western larch was less than one-half inch in diameter. On an average there were about 12½ knots in each 1 by 8 inch by 12 foot board. Most of the knots were black, but only about 1 in 50 was loose or rotten. The small size of the knots was especially evident in the common grades, where the knots averaged only one-half inch in diameter. The knots in the larch-fir mixture were about the same size as those in western larch, but there were more of them. Southern yellow pine knots, on an average, were about twice as large as those in western larch, but there were only about one-third as many. In Douglas fir (coast type) the knots were somewhat larger than in western larch, and there were about half as many. The small size and high quality of the knots in western larch make the common grades of the species suitable for a large variety of uses.

SHAKE

Shake occurs in western larch lumber with about the same frequency that it does in northern white pine, redwood, and shortleaf pine. The practice of long butting is largely responsible for the small amount of shake found in lumber. Six and one-half per cent of the western larch boards studied contained shake. In the select grades three-fourths or more of the shake was fine [9] or small.[10] On the other hand, over half of the shake in No. 3 common was through.[11]

The larch-fir mixture had less shake than western larch because the Douglas fir ("Inland Empire" type) contained shake in only 4½ per cent of the boards studied.

PITCH POCKETS

The pitch pockets in the western larch studied were smaller and less numerous than in other resinous woods. On an average about 1 western larch board in 10 had a small [12] or medium [13] pitch pocket. There were practically no large pitch pockets. Douglas fir (coast type) averaged about one pitch pocket to every 4 boards, while the hard pines averaged a pitch pocket to about every 3 or 4½ boards, depending on the species. The true firs, hemlocks, and southern cypress have no pitch pockets. Douglas fir ("Inland Empire" type) had a pitch pocket in about every sixth board. The larch-fir mixture, therefore, had more pitch pockets than western larch but not so many as Douglas fir (coast type) or the hard pines.

PITCH

Pitch occurs in western larch with about the same frequency that it does in Douglas fir (coast type). The pines, as a group, contain more pitch. In the western larch studied, about 1 board in every 20 contained pitch. Pitch occurred more frequently in the select

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[9] A fine shake is one with a barely perceptible opening.
[10] A small shake is one with an opening not over one thirty-second of an inch wide.
[11] A through shake is one extending from one surface through the piece to the opposite surface or adjoining surface.
[12] A small pitch pocket is not over one-eighth inch in width and not over 4 inches in length or not over one-fourth inch in width and not over 2 inches in length.
[13] A medium pitch pocket is one not over one-eighth inch in width and not over 8 inches in length or not over three-eighths inch in width and not over 4 inches in length.

than in common grades. Where pitch occurred it was principally of the light[14] or medium[15] rather than of the heavy[16] or massed[17] variety. Only about 1 western larch board in each 150 contained heavy or massed pitch, and these were boards in the No. 3 Common grade. The larch-fir mixture contained more pitch than did the western larch. The difference, however, was small, for only about 1 Douglas fir ("Inland Empire" type) board in 13 contained pitch.

PITCH STREAKS

Very few pitch streaks are found in western larch, fewer in fact than in any of the softwoods that are subject to pitch. The results of a survey by the Forest Products Laboratory show about 1 western larch board in 40 contained a pitch streak and that about two-thirds of the pitch streaks were small.[18] Pitch streaks occurred about twice as frequently in Douglas fir ("Inland Empire" type) as in western larch. Other resinous woods, depending on species, contained from three to seven times as many pitch streaks as western larch.

DECAY

Western larch lumber has relatively little decay. Out of 1,435 western larch boards studied only about 1 in 35 showed decay. All of the decay was of the incipient[19] variety, except in No. 3 Common where about one-third of the decay was advanced.[20] About twice as much decay was found in the Douglas fir ("Inland Empire" type) lumber as in western larch lumber. This was true also of the hard pines, western hemlock, and white fir. Western yellow pine was the only important commercial softwood whose lumber, as shipped from the mill, showed less decay than western larch. The small amount of decay found in western larch lumber is indicative of the sound, vigorous nature of the timber.

SEASONING DEFECTS

Western larch has a high percentage of checks and splits and a low percentage of stain. The prevalence of these defects is a reflection of the high shrinkage, low-splitting resistance, and narrow sapwood ring of the species. The extent of these defects is determined partly by seasoning practices and is, therefore, subject to control. They nevertheless indicate a natural tendency of the species and the necessity for exercising special care in seasoning.

CHECKS

Checks are the most prevalent of the seasoning defects. Over half of the western larch boards examined showed checks. The percentage was higher than that shown by any of the other softwoods

[14] Light pitch is a slightly evident presence of pitch.
[15] Medium pitch is a slightly more evident trace of pitch than is the light.
[16] Heavy pitch is the very evident presence of pitch shown by its color and consistency.
[17] Massed is a clearly defined accumulation of solid pitch in a body by itself in a piece of lumber.
[18] A small pitch streak is one not over one-twelfth the width by one-sixth the length of the surface on which it occurs.
[19] Incipient decay is an early stage of decay in which disintegration has not proceeded far enough to soften or otherwise change the hardness of wood perceptibly.
[20] Advanced decay is the older stage of decay in which disintegration is readily recognized because the wood has become punky, soft, and spongy, stringy, ring shaped, pitted, or crumbly.

studied. Douglas fir ("Inland Empire" type) showed about three-fourths as much checking as western larch, while Douglas fir (coast type) and southern yellow pine showed only about one-third as much. About three-fourths of the checking was end checks. Small checks [21] came next in frequency.

SPLITS

Splitting is a common defect in western larch. The same properties that are responsible for the prevalence of checking are also responsible for the prevalence of splitting. About one in every five western larch boards examined was split. Except in No. 3 Common the splits were all short [22] or medium [23]. The larch-fir mixture showed slightly less splitting than western larch. With one exception the other species studied showed less splitting than western larch. Douglas fir (coast type) showed about two-fifths as much and western white pine about the same amount of splitting.

STAIN

The stain in western larch is practically negligible. The small amount (about 1 piece in 60) that does occur is of light [24] variety. Douglas fir ("Inland Empire" type) showed about twice as much stain as the western larch. Redwood and eastern hemlock showed about the same amount, and all other species studied showed considerably more.

MANUFACTURING DEFECTS

The occurrence of manufacturing defects is only slightly influenced by species properties or characteristics. Comparison of the occurrence of manufacturing defects in western larch with those in other species is, therefore, not warranted.

Torn grain occurs more frequently in western larch than any other manufacturing defect. It is usually the result of a tearing or chipping of grain on one side of a knot. Since knots are more numerous in western larch than in most softwoods, the amount of torn grain is greater.

Skips, burns, punctures, and scant boards occur in all grades but are relatively unimportant as compared with the natural and seasoning defects. The frequency with which they occur under present manufacturing practice is shown in the discussion of the grades. These defects reflect the care used in manufacturing rather than the species characteristics.

GRADES AND THEIR CHARACTERISTICS

Rules applying to the classification, manufacture, and grading of western larch are published by the Western Pine Manufacturers' Association (*32*). The grade names and the broad divisions into grades shown in the official rules are in accord with the American lumber standards (*28*). The sizes of the rough and dressed lumber also follow closely the American lumber standards. Variations from

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[21] A small check is a perceptible opening not over 4 inches long.

[22] A short split is one whose length does not exceed either the width of the piece or one-sixth of its length.

[23] A medium split is one whose length exceeds the width but not one-sixth of the length.

[24] Light stain is a slight difference in color which will not materially impair the appearance of the piece if given a natural finish.

these standards are indicated in the grading rule books and are in all cases either slightly thicker or wider than the standards. According to the grading rules of the Western Pine Manufacturers' Association, Douglas fir ("Inland Empire" type) is considered of similar character and quality to western larch and is permitted in all grades of western larch.

The grading rules of the Western Pine Manufacturers' Association describe the grades by listing a number of typical examples under definitions that give the general characteristics of the grade. Written rules, however, have their limitations and can not cover all the possible types and variations to be found in the lumber of any grade. The examples given in the rule books do not, therefore, include all of the different types of boards to be found in a grade.

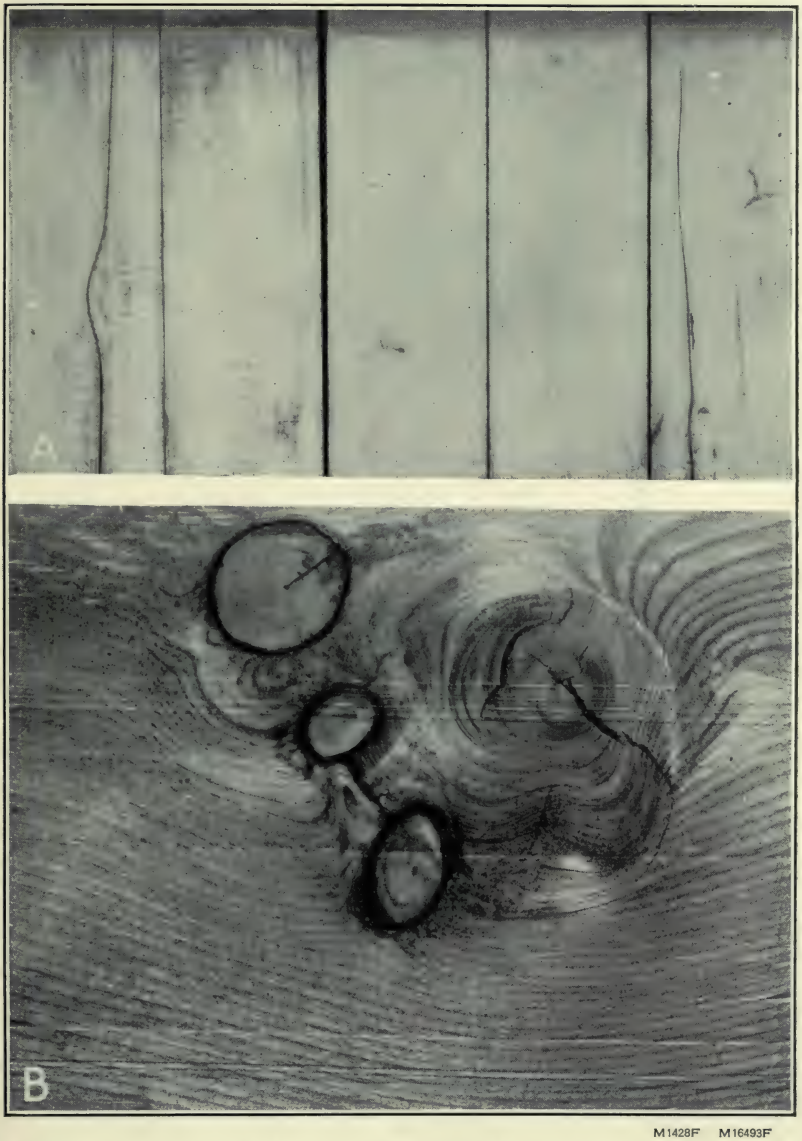
The description of grades given in this bulletin includes not only the limitations shown in the association rule book but also a detailed record of the defects found in the grade as marketed. This record presents the percentage of boards in which each defect was found. Since association grading rules are changed slightly from time to time, grade descriptions can not be considered unchangeable. Likewise the data on defects found in the grades are subject to change as a result of changes in grade descriptions, improved seasoning and dressing practice, and the collection of additional data.

GRADE YIELD AND PRODUCTION

The standard grading rules of the Western Pine Manufacturers' Association list the following grades of larch-fir lumber: Selects—C and better, and D; Common—Nos. 1, 2, 3, 4, 5; Dimension and timbers—Nos. 1, 2, 3.

The proportion of each grade produced by the present-day methods of manufacturing western larch and Douglas fir ("Inland Empire" type) is presented in Table 8. The grade-production percentages, which are given separately for western larch and Douglas fir, were obtained by means of detailed mill-scale studies. The larch-fir grade production figures given in the last column of the table are based on average shipments of the Western Pine Manufacturers' Association during a 5-year period which included the year the mill-scale studies were made. These figures check closely with the average obtained from the mill-scale study. They differ, however, from the figures shown in Table 9 which were obtained at a later date and which show a decided increase in the percentage of selects produced. The percentage of grades produced differs considerably, of course, among mills due in part to the manufacturing policy, the market cut for, and the quality of the log run.

The Western Pine Manufacturers' Association's grade-production figures based on a 5-year average (1924 to 1928, inclusive) are shown in Table 9. It may be noted that a number of the separate grades as classified under the standard grading rules are combined in actual practice. In the select grades the recognized grades of C and Better and D Select are sometimes marketed as D and Better. Mill-scale studies show that this grade is about two-thirds D Select and one-third C and Better Select. In the common grades of larch-fir lumber the general practice is to market No. 1 and No. 2 Common together or to sell all the better grades of common as No. 3 Common and Bet-



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A, The knots of western larch hold paint well. The boards shown have been exposed to weather at Madison, Wis., about two years. Small checks in the knots are the only evidence to indicate the presence of the knots under the paint coat; B, cluster knots in western larch boards. While not frequent in occurrence they occur more often in western larch than in other commercial softwoods

M12138F

Typical C and better western larch boards surfaced on two sides. The principal natural defects found in this grade are small or pin knots one-half inch or under in diameter and occasionally a small pitch pocket. The knots are tight, comparatively few in number, and scattered, as shown in *a*, *b*, and *c*. The grade contains a large proportion of boards like *d*, *e*, and *f*. The grain of *d*, *e*, and *f* is slightly raised, and *e* has a small puncture. Such boards give the grade, as a whole, a clear appearance. A single serious defect of any type is sufficient to prevent a board from entering the grade

ter. Mill-scale studies show that No. 2 Common and Better is practically a straight No. 2 grade with only an occasional No. 1 Common board. No. 3 and Better, however, is about one-half No. 3 Common and one-half Better. Table 9 shows also that certain classes of material have been separated from the regular recognized grade and sold as separate items. The marketing of timbers and planks as a separate class of material under the dimension group of grades is an example of this practice.

TABLE 8.—*Percentage of western larch and Douglas fir in larch-fir mixture*

Grade	Larch grade production by mills [1]					Average of all mills [1]		Western larch in mixture [2]	Douglas fir in mixture [2]	Average of all mills [1]	Larch-fir [3]
	Mill No. 1	Mill No. 2	Mill No. 3	Mill No. 4	Mill No. 5	Larch	Douglas fir			Larch-fir	
B and Better Selects	6.21					3.25	0.16	97.0	3.0	1.78	5.5
C Selects	.76	2.84	1.95		0.19	1.25	.13	94.0	6.0	.71	
D Selects	7.73	7.02	10.13	4.84	11.25	8.04	1.84	87.0	13.0	5.16	1.9
Total	14.70	9.86	12.08	4.84	11.44	12.54	2.13			7.65	7.4
Average								90.0	10.0		
No. 1 Common	.05		.03			.05	.02	79.0	21.0	.04	5.6
No. 2 Common	3.97	23.94	10.55	3.80	18.75	11.15	15.07	53.0	47.0	13.00	
No. 3 Common	9.22	18.38	8.67	2.96	18.79	12.40	15.59	54.0	46.0	13.94	19.2
No. 4 Common	1.01	4.88	4.16	.69	4.58	2.59	4.15	48.0	52.0	3.33	9.9
No. 5 Common	.13	.26	.09	.04	.17	.14	.23	48.0	52.0	.18	
Total	14.38	47.46	23.50	7.49	42.29	26.33	35.06			30.49	34.7
Average								53.0	47.0		
No. 1 Dimension and timbers	62.29	32.44	59.20	79.33	42.86	53.20	53.40	60.0	40.0	53.24	57.0
No. 2 Dimension and timbers	2.03	.04	3.90	7.11	3.33	2.04	2.48	55.0	45.0	2.26	
No. 3 Dimension and timbers	.09		.05	1.23	.08	.10	.18	45.0	55.0	.14	
Ties	6.47	10.20	1.27			5.77	6.74			6.22	
Total	70.88	42.68	64.42	87.67	46.27	61.11	62.80			61.86	57.0
Average								60.0	40.0		
Moldings	.04					.02	.01				.9
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00			100.00	100.00
Average								60.0	40.0		

[1] Based on a Forest Service mill-scale study.
[2] Based on percentage figures in columns 7 and 8 and on a mixture of 60 per cent larch and 40 per cent Douglas fir, which is the average ratio of the 10-year cut from 1919 to 1928.
[3] Based on shipments of the Western Pine Manufacturers' Association. Average over a 5-year period (1920–1924).

TABLE 9.—*Western larch grade production* [1]

(Basis 581,202,000 board feet)

Grade	Per cent	Per cent	Grade	Per cent	Per cent
No. 1 Dimension	35.6		No. 1 and 2 Common	2.7	
No. 2 Dimension	5.4		No. 3 and Better Common	5.1	
No. 3 Dimension	2.6	49.3	No. 3 Common	11.8	
Ties	1.1		No. 4 Common	8.6	30.5
Timbers and planks	4.6		No. 5 Common	.4	
C and Better Select	7.4		Short Common	1.0	
D and Better Select	.8		Select Common	.9	
D Select	2.2	10.6	Miscellaneous	9.6	9.6
Beveled siding					
Short selects	.2				

[1] Based on shipments of the Western Pine Manufacturers' Association. Average over a 5-year period (1924 to 1928, inclusive).

The combined grades of larch-fir give the consumer a high value. Western Pine Manufacturers' Association price figures, averaged over a 3-year period, 1926 to 1928, inclusive, show that D and Better grade sells for about $1.22 per thousand board feet less than it would if it were sold as two separate grades. The consumer, however, often can not or does not use the C and Better material in the combined grade to the best advantage. The practice of combining grades, therefore, tends to cause the consumer to use better grades than he requires, which is poor utilization. Manufacturers will eventually recognize that the combining of grades is not necessary in order to sell western larch and that they are losing money by it. The D and Better and No. 1 to 3 Common and Better combinations now so common on the market will, therefore, probably gradually be withdrawn.

HEARTWOOD CONTENT

Table 10 shows the heartwood content of each grade of western larch by classes. Very little western larch of any grade had less than three-fourths heartwood.

TABLE 10.—*Heartwood content of western larch boards*

Heartwood	Per cent of total number of boards of grade—			
	C and Better	D Select	No. 2 and Better	No. 3 Common
Per cent of cross section:				
0–54		0.4	1.0	0.4
55–64	1.1	.2	.5	1.5
65–74	1.5	.8	1.0	1.3
75–84	5.2	4.8	7.2	4.3
85–99	32.4	33.8	29.2	23.8
100	59.8	60.0	61.1	68.7
Total	100.0	100.0	100.0	100.0
Average heartwood	94.8	95.1	94.3	95.5
Basis—boards	269	477	209	462

WIDTH OF RINGS

Table 11 shows the width of rings in each grade of western larch by classes.

TABLE 11.—*Width of ring in western larch boards*

Rings per inch (number)	Per cent of total number of pieces of grades—				
	C and Better	D Select	No. 2 and Better	No. 3 Common	All grades
4				0.2	0.1
5–6			0.5	1.5	.6
7–8			2.9	5.6	2.3
9–12	0.4	1.5	4.8	10.4	4.8
13–17	7.0	7.3	15.4	18.6	12.2
18–22	17.0	17.2	19.2	19.0	18.1
23+	75.6	74.0	57.2	44.7	61.9
Total	100.0	100.0	100.0	100.0	100.0
Average	27.2	26.9	24.1	21.6	24.7

GRADE DESCRIPTIONS

SELECT GRADES

The select grades for western larch listed in the grading rules of the Western Pine Manufacturers' Association include C and Better and D. Lumber of these grades has, as a whole, a good appearance and is suitable for both natural and paint finishes. Items, such as ceiling, flooring, partition, wainscoting, molding, window and door casings, window and door frames, and finish, are manufactured from these grades.

Mill-scale studies indicate (Table 8) that only about 12½ per cent of D and Better larch is actually produced. This is a rather low production in view of the fact that western larch is capable of producing a higher percentage of material in the select grades than any other tree species in the "Inland Empire" region. Well-informed lumbermen estimate that the usual run of western larch logs should yield 27 per cent of the D and Better product. One Canadian mill, which produces over 25,000,000 feet of western larch annually, reports a 30 per cent production of the select grades.

There are two reasons for the present small production of western larch select grades. The excellent qualities of the western larch select grades for flooring, ceiling, and interior finish have not been generally recognized, and the relatively small price spread between grades has led to the conclusion, as a rule without any definite basis, that it does not pay to use refined methods with western larch. Ordinarily the log is sawed to get out the C and Better product, and at some mills the D Selects, which naturally develop in cutting such a high-quality log, are saved. However, at a good many plants select stock of the D grade is mixed with the common grades and sold as No. 3 and Better or No. 2 and Better. Much of the D product of the log now goes into low-class products, such as dimension, timbers, and ties. Such practices keep down the mill-run value of the species and also greatly hinder the producer who is attempting to cut and market the maximum amount of the select grades. If one can buy a grade of No. 3 Common and Better and obtain a good percentage of D grade or purchase dimension of the D grade at a price slightly over that for the common dimension, it becomes difficult to market the grade of D Select, particularly at a reasonable price. Such manufacturing and selling evils are now common practice in the western larch trade and decrease the profits obtainable from this wood.

The selling of western larch and Douglas fir ("Inland Empire" type) lumber in mixture as a single product, larch-fir, has a very decided effect upon the selling value and marketing of the western larch select grades. The Western Pine Manufacturers' Association reports show (Table 8) the 5-year average yield of larch-fir selects to be about 7.5 per cent. This compares closely with the grade production figure of 7.6 per cent for the two species, which was obtained by intensive mill-scale studies. The mill-scale data in Table 8 give very positive proof that the larch-fir select grade problem is primarily a western larch problem. Of the D and Better larch-fir produced, about 90 per cent is western larch, while the C and Better grade is made up of almost 97 per cent western larch. The Douglas fir, particularly the sapwood, is different in color from the western larch

and mars the uniformity of appearance which is so important in flooring and finish where natural finishes are employed. Difference in hardness of species is also objectionable in these items. A few of the more progressive manufacturers are excluding all Douglas fir from the C and Better grade. Although there is but little western larch sapwood, it would be well to exclude it from the C and Better grade. (Pl. 6.)

In D Select grade for interior uses where a natural finish is customary, it would also be a decided trade advantage if all sapwood were excluded. Such a practice should be entirely feasible, since sapwood could go into D Select products for outside uses where paint conceals the contrasting color of the western larch heartwood and sapwood. A straight run of larch selects should, moreover, command a higher price than one which includes some fir.

C AND BETTER SELECT

According to the standard grading rules of the Western Pine Manufacturers' Association, C and Better larch consists of C and all the better products of the log. The grade permits only a limited amount of small defects or blemishes. Small knots, limited in number and well scattered over the piece, are permitted in practically all of the items manufactured. In the absence of such knots or where the knots are very few in number, such defects as slightly raised or torn grain, small season checks, and very small pitch pockets are permitted. A serious combination of the above defects will not be allowed in any one piece, nor any defect that will destroy the high quality and appearance of the grade.

The defects in the grade as marketed by five mills in 1928 are shown in Table 12. The defects were of such a size and character that they did not detract greatly from the appearance or utility of the boards.

TABLE 12.—*Character and occurrence of defects in western larch C and Better grade*[1]

Kind of defect	Frequency of occurrence	General character
	Per cent	
Check	39	Three-fourths are end checks, remainder small.
Knots	35	Average about one-fourth inch in diameter. Half black, all tight. Knots over one-half inch in diameter found in about 1 board in 30.
Puncture	16	Small. Made by peavies, pike poles, etc.
Pitch pockets	10	Two-thirds very small. Few medium. None large.
Torn grain	9	Slight.
Burns	6	
Pitch	5	All light.
Wane	4	Relatively unimportant. Occur in only occasional boards.
Skip	4	
Split	3	
Shake	2	
Bark pocket	2	
Stain	2	
Wormholes	1	

[1] Based on 272 specimens of western larch 1 by 8 inches in size, studied by the Forest Products Laboratory.

Common regional practice is to cut for C and Better western larch at the head saw. Of the total amount of select material cut from the average western larch log, 36 per cent is of C and Better grade.

A considerable portion of the stock of this grade is manufactured into flooring, ceiling, partition, siding, wainscoting, molding, and finish.

D SELECT

D Select grade includes all stock between C and Better and the common grades and will admit quite serious defects, if at the same time the piece retains a good appearance. (Pl. 7.) The D grade of western larch provides an excellent stock for paint finishes, but includes as well a fair percentage for interior uses where a natural finish is customary. In this grade one cut is allowed in pieces 12 feet or longer if the resultant waste does not exceed 4 inches, provided the piece is otherwise better than average. Fine season checks over the entire face or several larger season checks are admitted in the D Select grade, as well as numerous small knots, pitch pockets, raised and torn grain or other defects common to western larch and Douglas fir that do not give a course or common appearance to the piece.

The defects in the grade as marketed in 1928 are shown in Table 13.

TABLE 13.—*Character and occurrence of defects in western larch D Select grade* [1]

Kind of defect	Frequency of occurrence	General character
	Per cent	
Knots	68	Average diameter one-third inch. Average number to board, two. All but few encased or partly encased. About 1 in 60 loose. Knots over 1 inch in diameter found in 1 board in 30.
Checks	60	Over one-half end checks. One-third small. Large checks rare. None through.
Torn grain	23	Responsible for some boards being in grade.
Puncture	18	About same as C grade. Seldom influenced grade.
Splits	11	Three-fourths short, balance medium.
Pitch	10	Seven-eighths light. One board in 100 contained medium.
Pitch pockets	10	One-half small. Two-fifths very small. Medium or large in 1 board in 75.
Skip	7	Occasional. Responsible for some boards in grade.
Burn	9	
Wane	6	
Pitch streak	3	Rare. Relatively unimportant.
Shake	3	
Wormhole	2	
Stain	2	
Bark pocket	1	
Decay	1	

[1] Based on 484 specimens of western larch 1 by 8 inches in size studied by the Forest Products Laboratory.

Practically all defects occur more frequently and in worse form in the D Select grade than in the C and Better grade. Knots and checks are about twice as frequent and are larger in D Select than in the C and Better grade. In addition the D Select grade differs from the C grade in that it contains boards with a serious defect which requires cutting.

In cutting for C and Better western larch at the head saw, some D Select naturally develops. This stock may or may not be utilized in the select grades. Entirely too large a proportion of the D Select grade is now put into dimension, timbers, and ties. Mill-scale studies show that approximately 64 per cent of the select material produced from the average run of larch logs is of the D Select grade.

COMMON GRADES

The standard grading rules of the Western Pine Manufacturers' Association provide that western larch common grades shall carry the same appearance, grade for grade, in the general measurement of defects as western yellow (Pondosa) pine. The rules, therefore, include specifications for No. 1, No. 2, No. 3, No. 4, and No. 5 Common boards. The characteristics of western larch common grades as distinguished from the select grades are a general coarseness of appearance caused by various defects in a greater or less degree according to grade. The numerous defects and blemishes that common western larch lumber may contain preclude its use for finishing purposes. Common lumber of western larch is suitable for general utility and construction purposes.

The following grades of common western larch lumber are available on the market: Select Common, No. 1 and 2 Common, No. 3 and Better Common, No. 3 Common, No. 4 Common, and No. 5 Common.

Douglas fir ("Inland Empire" type) is permitted in all grades of western larch. The Douglas fir ("Inland Empire" type), which is generally of poorer quality than the western larch, produces considerably more stock of the grades of common lumber and dimension. Mill-scale studies (Table 8) show that Douglas fir produces 35 per cent of its lumber in the common grades, as compared with 26 per cent for western larch. Larch-fir common lumber, however, contains about the same amount of each species.

NO. 1 COMMON

Mill studies have shown (Table 8) that only one two-thousandths or one-twentieth of 1 per cent of the western larch cut falls into the grade of No. 1 Common. No. 1 Common western larch is usually combined with No. 2 Common and sold as No. 1 and 2 Common. This grade is suitable for shelving, cornice, fine barn board, and all uses where best quality and appearance of common lumber are required.

No. 1 Common western larch boards and strips include all sound, tight-knotted stock with the size of the knot the determining factor of the grade. Knots, light pitch, season checks, and small pitch pockets are admissible in No. 1 Common grade if they do not affect the general utility of the piece in which they occur. So small is the percentage of No. 1 Common produced in western larch that no study was made of the characteristic defects of the species in this grade.

NO. 2 COMMON

Eleven per cent of the cut of the average western larch log falls into the grade of No. 2 Common. This grade averages approximately 42 per cent of the total cut of common western larch lumber. In practice No. 2 Common western larch is sold in mixture with No. 1 Common and ordinarily makes up the bulk (99 per cent) of the grade. (Pl. 8.)

No. 2 Common western larch is subject to the same inspection as No. 1 Common except that coarser and larger knots not necessarily sound, or their equivalent, form the basis of inspection. Some of the most common types of knots admissible in this grade are large

knots, branch knots, checked knots, and those not firmly set in the piece. Other defects permitted in the grade are season checks, heart shake, pitch, and pitch pockets. No serious combination of the above defects is admissible in any one piece.

No. 1 and No. 2 Common were combined in the study of the characteristic defects. The defects shown by these combined grades sold as No. 2 and Better are shown in Table 14.

TABLE 14.—*Character and occurrence of defects in No. 2 Common and Better western larch* [1]

Kind of defect	Frequency of occurrence	General character
	Per cent	
Knots	91	Average diameter one-half inch. Average number to board, 13. 93 per cent 1 inch or less in diameter. About one-third are intergrown. Loose knots occur in about 1 board in 6.
Checks	69	Four-fifths end checks, rest small and medium.
Splits	13	One-third short and two-thirds medium.
Pitch pockets	10	Four-fifths very small. Remainder small or medium. None large.
Torn grain	8	Unimportant in determining grade.
Burn	8	Do.
Shake	7	One-half small. 1 board in 70 contains through shake.
Skip	6	
Puncture	5	Small.
Wane	5	
Pitch streaks	4	Two-thirds small. One-third medium. None large.
Wormholes	4	Small and scattered.
Decay	1	Rare. Relatively unimportant.
Pitch	1	

[1] Based on 211 specimens of western larch 1 by 8 inches in size studied by the Forest Products Laboratory.

No. 2 Common grade differs from the select grades principally in size and number of natural defects. Natural defects, except wane and pitch defects, are larger and more numerous in No. 2 Common than in the select grades. Manufacturing defects are about as frequent in the No. 2 Common grade as in the select grades. Punctures are less frequent in No. 2 Common than in the select grades because the boards forming the grade come from nearer the pith of the tree. Seasoning defects are somewhat more frequent and injurious in No. 2 Common than in the D Select grade.

No. 2 Common and Better is of a character that fits it for doors, flooring, partition, molding, siding, sheathing, subflooring, and roofing.

NO. 3 COMMON

The grade of No. 3 Common western larch comprises much of the lower product of the log. Although the appearance of a part of the stock is coarse, it is a good general utility grade having a wide variety of uses. (Pl. 9.) No. 3 Common makes up approximately 47 per cent of all the common lumber cut from the average western larch log. Seventy per cent of the No. 3 Common western larch produced is sold separately under that grade name. The remainder is sold in combination with No. 1 and No. 2 Common as No. 3 and Better Common.

Some of the defects permitted in the No. 3 Common grade are large, loose, or unsound knots, large spike knots, occasional knot holes, season checks, skips and roller splits, some red rot, and con-

siderable heart shake. A serious combination of the above defects is not admissible in any one piece. The defects found in the grade as marketed are shown in Table 15.

TABLE 15.—*Character and occurrence of defects in No. 3 Common western larch* [1]

Kind of defect	Frequency of occurrence	General character
	Per cent	
Knots	98	Average diameter one-half inch. Average number to board, 17. Ninety per cent 1 inch or less in diameter. Few black. One loose knot in every two boards.
Checks	69	Two-thirds end, one-fourth small or medium. One board in 18 has through check.
Splits	30	About equally divided between short and medium. One board in 37 has long.
Torn grain	25	Unimportant in determining grade.
Wane	11	
Pitch pockets	9	About two-thirds are very small. One-third small. About 1 board in 300 contains large pitch pockets.
Pith	9	
Skip	9	
Shake	8	Over half through, one-third fine or small.
Burn	8	
Puncture	7	
Pitch	6	One-half light, one-third medium. About 1 board in 150 has heavy or massed pitch.
Scant	6	
Decay	4	Two-thirds incipient, one-third advanced.
Pitch streak	3	Rare. Relatively unimportant.
Pitch seam	3	
Wormholes	2	
Bark pockets	2	
Stain	1	

[1] Based on 468 specimens of western larch 1 by 8 inches in size studied by the Forest Products Laboratory.

All natural defects, except various pitch defects, are more frequent in the No. 3 Common than in No. 2 Common. The size of defects in No. 3 Common does not differ greatly from that of No. 2 and Better, but defects are generally of lower quality. Manufacturing defects, except torn grain, occur with about the same frequency in No. 3 Common as in No. 2 and Better. Of the seasoning defects, checking is about the same in No. 3 Common as in No. 2 and Better, but the splits are more than twice as common and are larger in the No. 3 Common.

No. 3 Common western larch is used extensively as siding, flooring, partition, sheathing, subflooring, roofing, concrete forms, scaffolding, plaster grounds, and boxes.

NO. 4 AND NO. 5 COMMON

The defects common to No. 4 Common grade are much the same as those found in No. 3 Common, but exist in more serious combination or to a greater degree. (Pl. 10.) Approximately 10 per cent of the total cut of western larch common falls within the No. 4 Common grade.

No. 5 Common is the lowest recognized grade and admits all defects known in lumber, provided the piece is strong enough to hold together when carefully handled. Highly defective western larch or Douglas fir ("Inland Empire" type) trees are seldom cut in the woods; consequently not many greatly defective logs ever reach the mill. The cut of No. 5 Common larch-fir is less than 1 per cent

M12137F

Typical D select western larch board surfaced on two sides. Board *a* has a combination of knots and raised grain; *b* has a knot, bark pocket, and checks; *c* has intergrown knots over one-half inch diameter and black incased knots under one-half inch; and *d* has six black incased knots under one-half inch and a machine gouge. Boards *e* and *f* have loose knots which can be cut out and thus give two practically clear pieces

M12139F

Typical No. 1 and 2 Common or No. 2 and Better Common western larch boards. The knots are all tight, but not necessarily sound. Boards *a* and *b* have numerous black incased knots, all tight and under 1 inch in diameter; *c* and *d* have numerous intergrown or partially intergrown knots under 2 inches in diameter and also a few small, tight, incased knots under 1 inch in diameter; *e* has only a few incased knots, but some are 1 inch or larger in diameter and though tight may loosen under adverse conditions; *f* has small intergrown knots under one-half inch in diameter and intergrown and partially intergrown spike knots. Board *f* is typical of the western larch boards obtained from near the pith of the log

M12135F

Typical No. 3 Common western larch boards surfaced on two sides. Planer checks, loose, broken, and black knots, and torn grain around knots are defects most commonly found in this grade. Occasionally boards contain a knot hole. The knots in boards *a*, *b*, and *c*, are all tight, but are over 2 inches in diameter and are either checked through or broken. Boards *d*, *e*, and *f* have fewer knots than boards *a*, *b*, and *c* but the knots are of poorer quality. In addition, *e* has knot holes and through checks, and *f* has a through puncture

M12136F

Typical No. 4 Common western larch boards surfaced on two sides. Boards *a* and *c* are in the grade because of serious seasoning or planer checking. The knots are small and tight. Boards *b*, *d*, and *e* are in grade because of holes or the size or quality of the knots. The knots are large, loose, decayed, or broken. Board *f* contains serious check combined with large knots. Boards containing decay are also found in this grade

of the total common lumber of these species produced. No study was made of the defects in No. 4 or No. 5 Common western larch, as the value of these grades and the type of uses to which they are put are such that a detailed study of their defects is not warranted.

DIMENSION AND TIMBER GRADES

The dimension and timber grades from a quantitative standpoint are the most important grades applicable to the larch-fir mixture. Sixty-one per cent of the cut of the average western larch log goes into dimension, timbers, and ties. Sawed railroad ties make up approximately 6 per cent of the total western larch cut for the dimension and timber grades. Western larch and Douglas fir are considered excellent material for construction and heavy-duty stock, and it is for this reason that such a high percentage of the cut goes into the dimension grades. The fact that No. 1 larch-fir dimension has a selling value almost equal to that of the very best grades of common lumber is another reason for its large production. At present a good percentage of the product of the log that should be in the D grade is put into dimension, timber, and ties.

Three grades of dimension and timber are recognized under the standard grading rules of the Western Pine Manufacturers' Association; namely, No. 1, No. 2, and No. 3 Dimension and No. 1 and No. 2 Timbers. Sales of ties and timbers and planks are often made separately.

The dimension and timber grades do not specifically limit defects injurious to the strength; consequently the strength of material in these grades depends almost entirely upon the judgment of the graders, which varies considerably. Timbers of the foregoing grades, therefore, show such a wide range of strength that it is impracticable to assign safe working stresses to the grades; however, the Western Pine Manufacturers' Association have recently prepared structural grades for Douglas fir and western larch that do limit the defects. These new grades conform to the basic requirements for structural material of the American lumber standards and, although not commonly carried in stock by mills, may be had on special order.

NO. 1 DIMENSION AND TIMBERS

A mill-scale study showed that 96 per cent of the larch-fir dimension and timbers produced is of the No. 1 grade. The specifications of the No. 1 grade are therefore the most important of dimension and timber grades.

The rules of the Western Pine Manufacturers' Association specify that No. 1 Dimension and Timbers must be of a good sound character but will admit of defects that do not impair the strength of the piece. On the basis of a 2 by 4 inch piece, wane on edge is admissable one-half inch deep for half of the length, or a proportionate amount for a shorter distance on both edges. In any case, one side and two edges should allow a good nailing surface. "Small dimension must be moderately straight, and larger dimension must be more so. A few wormholes are admissable."

The strength of material of the grade will vary widely, both because of mixture of species and because there are no specific limi-

tations of defects injurious to strength. It can be used to advantage where the user has widely varying strength requirements and can sort the material into strength classes. Such a sorting or regrading can be made with the aid of the basic provisions of the American lumber standards for structural material (*28*).

No. 1 Dimension can not be recommended for uses where uniformly high strength is essential because of uncertainty as to strength of the weaker pieces. The working stresses recommended for western larch on page 60 are only applicable when the material has been regraded to meet the American lumber standards basic provisions for select and common grades.

NO. 2 DIMENSION AND TIMBERS

Less than 4 per cent of the dimension and timbers produced from the average western larch log is of the No. 2 Dimension grade. Under the rules of the Western Pine Manufacturers' Association material of this grade will "admit of large, coarse knots, not necessarily sound, considerable wane, also shake, wormholes, dozy streaks, crooked pieces or other defects which weaken or impair the pieces to such an extent as to render it unfit for No. 1 grade. A serious combination of these defects is not admissible in any one piece."

The decay streaks and unsound knots admissible in the grade may reduce the strength to less than half that of clear wood. Timbers and dimensions of this grade are therefore not suitable for use where great strength is desired. They are used for temporary structures and where stiffness rather than bending strength is desired. Even in such structures the pieces containing decay should be sorted out and used where strength is relatively unimportant.

NO. 3 DIMENSION AND TIMBERS

Only about one-quarter of 1 per cent of the western larch dimension and timbers produced are of the No. 3 grade. The rules of the Western Pine Manufacturers' Association "admit a great deal of rot and all the imperfections allowed in No. 1 and No. 2, but in a much more pronounced form." The grade is suitable for use only where strength requirements are of practically no importance or where the material is cut to short lengths and the more injurious defects eliminated.

WORKING STRESSES FOR DIMENSION AND TIMBER

Working stresses are assigned strength values used to determine the safe load-carrying capacity of timbers or the size and number of timbers necessary to safely carry a given load. They are intended primarily for use in design of structures and are therefore a basic limitation imposed by building codes or other engineering specifications.

The working stresses shown in Table 16 were obtained by adjusting the strength of the clear wood to meet conditions which exist in service (*18*). Such adjustment is made to take care of the reduction in strength due to the knots and other defects permitted by the grade specifications, the occurrence of pieces below the average strength, the lower strength shown by wood subjected to long-time loads from that shown by test specimens which are loaded only a

few minutes, and the weakening effect of certain species characteristics. In addition the working stresses in Table 16 provide for a factor of safety (*27*) to take care of accidental overloads up to one and one-half times the design load. The adjustment for the injurious effect of defects of necessity limits the application of working stresses to a specific grade of a species except in the case of modulus of elasticity and compression perpendicular to the grain, which are not seriously affected by defects. Values for these two properties are therefore applicable to all grades.

A comparison of western larch with other species based on the working stresses will differ from a comparison based on the strength of clear wood. This is due primarily to the fact that the strength values for clear wood are an average obtained from tests, whereas working stresses are based on engineering judgment, which takes into consideration not only the strength of the clear wood but also species characteristics, characteristic defects, results of tests on structural sizes, and all other available data.

The working stresses for western larch are conservative; that is, they are lower than would appear necessary for the strength shown by the clear wood. The comparatively low values assigned to some of the properties for western larch in Table 16 are due to results obtained in tests of structural timbers (*9*, *11*).

The working stresses of Table 16 are applicable only to timbers graded in accordance with the basic requirements of American lumber standards for structural material (*28*). The dimension and timber grades of western larch previously discussed do not meet these requirements. It is possible, however, to use the working stresses recommended in Table 16 with timbers purchased on special orders provided the specifications embody the basic principles for structural material of American lumber standards (*28*). American lumber standards provide structural-grade examples which make it easy to prepare such specifications. The application of the working stresses to dimensions or to stock timber of the Western Pine Manuturers' Association grades (*32*) requires regrading. Such a regrading is not difficult to accomplish with the aid of structural-grade examples (*28*) and will result in all but a small percentage of timber falling into one of two grades. Timbers falling outside these grades can be used where great strength is not essential.

The working stresses recommended for western larch can not be safely used in all cases with the larch-fir mixture. The stiffness of western larch and Douglas fir ("Inland Empire" type) is practically the same, and the modulus of elasticity values in the last column of Table 16 can be safely used with the larch-fir mixture. Likewise, the working stresses for western larch under the heading, Fiber Stress in Bending, can be used for the larch-fir mixture because of the conservative nature of fiber stress in bending values for western larch. Working stresses for western larch in horizontal shear and compression parallel and perpendicular to the grain are not applicable to the larch-fir mixture. The values recommended for Douglas fir (Rocky Mountain type) rather than those for western larch must be used with larch-fir. The difference in the values recommended for western larch and Douglas fir (Rocky Mountain type) in compression and shear is sufficiently large to justify a separation of the species in most cases.

TABLE 16.—*Working stresses, in pounds per square inch, for select and common grades of timber conforming to the American lumber standards basic provisions for structural material* [1]

(As recommended by the Forests Products Laboratory)

Species	Fiber stress in bending [2]										Compression perpendicular to grain			Horizontal shear [3]		Compression parallel to grain (short columns having ratio of length to least dimension of 11 or less)						Average modulus of elasticity [4] (not varied with conditions of exposure or with grade)
	Continuously dry		Occasionally wet but quickly dried				More or less continuously damp or wet				Continuously dry	Occasionally wet but quickly dried	More or less continuously damp or wet	Not varied with conditions of exposure		Continuously dry		Occasionally wet but quickly dried		More or less continuously damp or wet		
	All thicknesses		Material 4 inches and thinner		Material 5 inches and thicker		Material 4 inches and thinner		Material 5 inches and thicker													
	Select	Common	Select	Common	Select	Common	Select	Common	Select	Common	Select and common			Select	Common	Select	Common	Select	Common	Select	Common	
Ash, black	1,000	800	800	680	900	720	710	600	800	640	300	200	150	90	72	650	520	550	440	500	400	1,100,000
Ash, commercial white	1,400	1,120	1,070	910	1,200	960	890	760	1,000	800	500	375	300	125	100	1,100	880	1,000	800	900	720	1,500,000
Aspen and large tooth aspen	800	640	580	490	650	520	440	370	500	400	150	125	100	80	64	700	560	550	440	450	360	900,000
Basswood	800	640	580	490	650	520	440	370	500	400	150	125	100	80	64	700	560	550	440	450	360	900,000
Beech	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800	500	375	300	125	100	1,200	960	1,100	880	900	720	1,600,000
Birch, paper	900	720	670	570	750	600	530	450	600	480	200	150	100	80	64	650	520	550	440	450	360	1,000,000
Birch, yellow and sweet	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800	500	375	300	125	100	1,200	960	1,100	880	900	720	1,600,000
Cedar, Alaska	1,100	880	890	760	1,000	800	800	680	900	720	250	200	150	90	72	800	640	750	600	650	520	1,200,000
Cedar, western red	900	720	710	600	800	640	670	570	750	600	200	150	125	80	64	700	560	700	560	650	520	1,000,000
Cedar, northern and southern white	750	600	580	490	650	520	530	450	600	480	175	140	100	70	56	550	440	500	400	450	360	800,000
Cedar, Port Orford	1,100	880	890	760	1,000	800	800	680	900	720	250	200	150	90	72	900	720	825	660	750	600	1,200,000
Chestnut	950	760	760	650	850	680	620	530	700	560	300	200	150	90	72	800	640	700	560	600	480	1,000,000
Cottonwood, eastern and black	800	640	580	490	650	520	530	450	600	480	150	125	100	80	64	700	560	550	440	450	360	900,000
Cypress, southern	1,300	1,040	980	830	1,100	880	800	680	900	720	300	225	200	100	80	1,100	880	1,000	800	800	640	1,200,000
Douglas fir (western Washington and Oregon type) [5]	1,600	1,200	1,233	983	1,387	1,040	948	756	1,067	800	[6] 347	[6] 240	[6] 213	90	72	1,173	880	1,067	800	907	680	1,600,000
Douglas fir (dense) [5]	1,750	1,400	1,349	1,147	1,517	1,213	1,037	882	1,167	933	379	262	233	105	84	1,283	1,027	1,167	933	992	793	1,600,000
Douglas fir (Rocky Mountain type)	1,100	880	800	680	900	720	620	530	700	560	275	225	200	85	68	800	640	800	640	700	560	1,200,000
Elm, rock	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800	500	375	300	125	100	1,200	960	1,100	880	900	720	1,300,000
Elm, slippery and American	1,100	880	800	680	900	720	710	600	800	640	250	175	125	100	80	800	640	750	600	650	520	1,200,000
Fir, balsam	900	720	670	570	750	600	530	450	600	480	150	125	100	70	56	700	560	600	480	500	400	1,000,000
Fir, commercial white	1,100	880	800	680	900	720	710	600	800	640	300	225	200	70	56	700	560	700	560	600	480	1,100,000
Gum, red, black, and tupelo	1,100	880	800	680	900	720	710	600	800	640	300	200	150	100	80	800	640	750	600	650	520	1,200,000
Hemlock, eastern	1,100	880	800	680	900	720	710	600	800	640	300	225	200	70	56	700	560	700	560	600	480	1,100,000

Hemlock, western	1,300	1,040	980	830	1,100	880	800	680	900	720	300	225	200	75	60	900	720	900	720	800	640	1,400,000
Hickory (true and pecan)	1,900	1,520	1,330	1,130	1,500	1,200	1,070	910	1,200	960	600	400	350	140	112	1,500	1,200	1,200	960	1,000	800	1,800,000
Larch, western	1,200	960	980	830	1,100	880	800	680	900	720	325	225	200	100	80	1,100	880	1,000	800	800	640	1,300,000
Maple, sugar and black	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800	500	375	300	125	100	1,200	960	1,100	880	900	720	1,600,000
Maple, red and silver	1,000	800	800	680	900	720	620	530	700	560	350	250	200	100	80	800	640	700	560	600	480	1,100,000
Oak, commercial red and white	1,400	1,120	1,070	910	1,200	960	890	760	1,000	800	500	375	300	125	100	1,000	800	900	720	800	640	1,500,000
Pine, southern yellow [5]	------	1,200	------	983	------	1,040	------	756	------	800	[6]	[6]	[6]	------	88	------	880	------	800	------	680	1,600,000
Pine, southern yellow (dense) [5]	1,750	1,400	1,349	1,147	1,517	1,213	1,037	882	1,167	933	379	262	233	128	103	1,283	1,027	1,167	933	992	793	1,600,000
Pine, northern white, western white, western yellow, and sugar	900	720	710	600	800	640	670	570	750	600	250	150	125	85	68	750	600	750	600	650	520	1,000,000
Pine, Norway	1,100	880	890	760	1,000	800	710	600	800	640	300	175	150	85	68	800	640	800	640	700	560	1,200,000
Poplar, yellow	1,000	800	800	680	900	720	710	600	800	640	250	150	125	80	64	800	640	700	560	600	480	1,100,000
Redwood	1,200	960	890	760	1,000	800	710	600	800	640	250	150	125	70	56	1,000	800	900	720	750	600	1,200,000
Spruce, red, white, and Sitka	1,100	880	800	680	900	720	710	600	800	640	250	150	125	85	68	800	640	750	600	650	520	1,200,000
Spruce, Engelmann	750	600	580	490	650	520	440	370	500	400	175	140	100	70	56	600	480	550	440	450	360	800,000
Sycamore	1,100	880	800	680	900	720	710	600	800	640	300	200	150	80	64	800	640	750	600	650	520	1,200,000
Tamarack (eastern)	1,200	960	980	830	1,100	880	800	680	900	720	300	225	200	95	76	1,000	800	900	720	800	640	1,300,000

[1] American lumber standards: Basic provisions for American lumber standards grades are published in Simplified Practice Recommendation 16 (*28*); specifications for grades conforming to American lumber standards are published in the 1927 standards of the American Society for Testing Materials, and in American Railway Engineering Association Bulletin 284 (*2*).

[2] Stress in tension: The working stresses recommended for fiber stress in bending may be safely used for tension parallel to grain.

[3] Joint details: The shearing stresses for joint details may be taken for any grades as 50 per cent greater than the horizontal shear values for the select grade.

[4] Factors to be applied to average modulus of elasticity values: The values for modulus of elasticity are average for species and not safe working stresses. They may be used as given for computing average deflection of beams. When it is desired to prevent sag in beams values one-half those given should be used. In figuring safe loads for long columns values one-third those given should be used (*28*).

[5] Exact figures given: In order to preserve the exact numerical relations among working stresses for grades involving rate of growth and density requirements the values for Douglas fir (western Washington and Oregon type) and for southern yellow pine have not been rounded off, as have the values for the other species.

[6] Working stresses for the Common grade: The values given are for the Select grade. Working stresses in compression perpendicular to grain for the Common grades of Douglas fir (western Washington and Oregon type) and southern yellow pine are 325, 225, and 200, respectively, for continuously dry, occasionally wet but quickly dried, and more or less continuously damp or wet conditions.

USES OF WESTERN LARCH

Western larch is an excellent general-utility wood. It is one of the strongest and hardest of our native softwoods; it has good decay-resistance and nail-holding power; the annual-growth rings are narrow and of uniform width; it glues well; it has a pronounced figure and can be given natural, polished, or paint finishes. On the other hand, certain of its properties, such as strength, nail-holding power, slow response to moisture changes, and its narrow and uniform width of annual-growth rings are sufficiently outstanding to warrant its consideration for special uses that require exceptional combinations of properties and characteristics. Primarily, western larch is a general-use wood, but a portion, possibly a selected portion, of the cut should be marketed as a specialty wood.

The suitability of western larch for any use must be determined largely from a comparison of its properties with the requirements of the use under consideration. Information on the properties of western larch is comprehensive and fairly complete. Information on use requirements, however, is in most cases based on observation and experience rather than on the results of laboratory or service tests. Complete information on use requirements will never be available because the uses are too numerous. Furthermore, the requirements of common and typical uses will vary enough with time and conditions to change the order of importance of the properties, if not to change entirely the actual properties required.

The discussions of uses of western larch in this bulletin are examples intended to illustrate how the data on the properties of western larch can be applied to determine the suitability of the wood for a use. The uses dealt with have been selected because of the amount of lumber consumed by them, the amount of western larch consumed by them, or because a study of properties and requirements indicates a possible market for western larch.

Table 17 is a list of some of the uses to which western larch and larch-fir commonly is put. The general grade or quality of material usually purchased for the various uses is also shown. The list is of interest principally as an indication of present practice, and it is not intended to imply that western larch is the best wood available for the various uses listed. In many cases several grades of material are shown to be employed in a single use. This apparent lack of definite grade requirements is due in part to different grades being required for different parts, but more generally to the range in the quality of the finished products and to differences in design influencing the grade requirements.

BUILDING MATERIAL

The properties of western larch adapt it for use in practically all the wood items used in buildings; consequently the bulk of western larch cut goes into building material. The properties that especially adapt western larch for building material are strength, decay resistance, and nail-holding power. Western larch is especially suited to those building material items for which it is impossible to predict the use requirements or conditions at the time of purchase. For example 8/4-inch dimension may be used for rafters, headers,

studding, or joists where bending strength, stiffness, and nail-holding power are desired but decay resistance is of little importance, or it may serve for sills or floor boards, which have some decay hazard. In adaptability to a wide range of building items western larch is similar to Douglas fir (all types) and southern yellow pine. The larch-fir mixture is not quite so adaptable for building items as western larch.

TABLE 17.—*Grade or form of western larch purchased for various uses*

Use	Grade		Form		Use	Grade		Form	
	Select	Common	Dimension, planks or timbers	Round, hewed, or split		Select	Common	Dimension, planks or timbers	Round, hewed, or split
Casings (window and door)	x				Poles and piling				x
Ceiling	x	x	x		Posts			x	x
Doors	x	x			Shelving		x		
Flooring	x	x			Snow fencing		x		
Frames (window and door)	x				Crossties			x	x
Partition	x	x			Well curbing		x	x	
Moldings and finish	x	x			Box crating		x	x	
Siding	x	x			Car construction	x	x	x	
Wainscoting	x				Caskets and coffin boxes	x	x		
Posts, girders, mud sills, stringers			x		Cooperage	x	x		
Planking, bracing			x		Electric machinery and appliances	x	x		
Bridge ties			x		Farm implements	x	x		
Joists, studding, rafters			x		Furniture and fixtures	x	x		
Sheathing, subflooring, roofing		x			Incubators and brooders	x	x		
Concrete forms, scaffolding		x	x		Refrigerators	x	x	x	
Plaster grounds lath		x			Screens (windows and doors)	x			
Corn cribbing			x		Signs		x	x	
Cross arms			x		Tanks and water troughs		x		
Culverts			x		Vehicles (wagon and automobile)	x	x		
Flumes and conduits			x		Wood-block paving			x	
Gates and fences		x	x		Woodenware	x	x		
Grain doors		x							
Mine timbers				x					

COMMON BOARDS AND SHIP-LAP

Common boards and ship-lap are not manufactured for a specific use. Not only are they used for a number of purposes in building, but they also go into a wide variety of other uses. Common boards and ship-lap are therefore general-utility items for which the strength, decay resistance, and nail-holding ability of western larch are especially adapted. Western larch boards can be used for concrete forms where strength is required, for roofing boards where strength and nail-holding power are required, and for drip boards, where some decay resistance is required.

About one-fourth of the cut of western larch and one-third of the cut of Douglas fir (Inland Empire type) go into common boards and ship-lap. Less than one-half of 1 per cent are of No. 1 Common grade. The bulk of the common boards and ship-lap is sold as No. 2 Common and No. 3 Common, or as No. 3 and Better. Some boards, about 1 per cent, are sold as No. 4 and No. 5 Common. Western larch common boards usually range from 4 to 10 inches in

width; a few boards, less than one-half of 1 per cent, are 12 inches or more in width.

Boards and ship-lap of the less decay resistant, lighter weight and weaker species have some advantage for certain uses over western larch. They are easier to cut, saw, nail, and handle, and hold paint better. When the final use can be anticipated before purchase these properties should be weighted against the greater strength, moderate decay resistance, hardness, and nail-holding power of western larch. The following discussion of individual uses of boards shows how the properties can be used in comparisons for specific rather than general uses.

SUBFLOORS

A number of species, including western larch, are successfully used for subfloors. This is due to the facts that under standard methods of construction there is little danger of floors failing mechanically and that the decay hazard is small. Western larch subfloors are very similar in ease of construction and serviceability to those of Douglas fir and southern yellow pine. Western larch subfloors are stronger and stiffer and hold nails better than those of the hemlocks, spruces, or true firs. On the other hand, western larch subfloors require more time to construct than hemlock, spruce, and true fir subfloors, which are softer and lighter species and consequently easier to work and handle. The lighter-weight species also stay in place better than western larch principally because of their smaller shrinkage. The moderate decay resistance of western larch, however, is some protection against decay hazards resulting from faulty plumbing, drip from ice-boxes, and other sources of moisture.

SHEATHING

Large amounts of western larch, especially of the No. 3 Common and Better grade, are used for sheathing. Where western larch is used for sheathing it is primarily because of the small size and tightness of the knots rather than because of the properties of the clear wood. The strength and moderate decay resistance of western larch are of little practical importance in sheathing, for the efficiency with which sheathing ties members into units depends upon nailing rather than the strength of the wood, and sheathing is so protected that it seldom decays. Capacity to stay in place is desirable to reduce to a minimum the passage of air and heat through cracks. Ease of working is desirable in that it speeds up and reduces the cost of construction. Tendency for cracks to open, however, is dependent more on the thoroughness of seasoning than on the capacity of species to stay to place. Ease of working influences cost but not service. Comparison of western larch with other species for sheathing should therefore be made largely on how well wood stays in place, tightness of knots, thoroughness of seasoning, and cost after adjusting for differences in ease of working.

ROOFING BOARDS

Western larch has a good combination of the properties desired for roofing boards. It will hold shingles or other roofing well, for it has a high nail-holding power and retains its nail-holding power

well with moisture changes. (Fig. 19.) Of the softwoods commonly used for roofing boards, only Douglas fir and southern yellow pine are stiffer than western larch. The moderate decay resistance of western larch, which is a desirable property should leaks develop, is about the same as that of Douglas fir. The tendency of western larch to split under roofing nails is slightly less than with Douglas fir. In ease of working, western larch is similar to Douglas fir and southern yellow pine but is harder to cut, saw, and nail than the hemlocks, true firs, and spruces.

Western larch roofing boards are obtained almost entirely from the No. 2 Common and No. 3 Common grades, which are always a larch-fir mixture. Roofing boards of larch-fir mixture are not equal to those of western larch alone. While they have the same stiffness they are slightly weaker in bending, contain more sapwood, and have a wider range in hardness. The difference in value, however, would probably not justify the cost of separating the species.

In so far as properties are concerned, there is little choice between larch-fir roofing boards and those of Douglas fir and southern yellow pine. As between larch-fir and the spruces, hemlocks, and true firs, the larch-fir roofing boards hold nails better, are stiffer, and more decay resistant, but are heavier and harder to cut, saw, and handle.

MISCELLANEOUS FARM USES

Western larch is a good general-utility wood; consequently the boards and ship-lap of the species have a wide range of usefulness on the farm. The hardness and strength of western larch boards adapt them to the heavy loads and rough usage to which the floors of many farm buildings are subjected, and their moderate decay resistance enables them to be used in pens, coops, troughs, and cribs that are subject to moderate decay hazards. The range of use of western larch boards is very similar to that of Douglas fir (coast type) and southern yellow pine; it is not so wide as that of southern cypress, but is wider than those of the true firs, hemlocks, and spruces. Because of paint-holding characteristics, ease of working, and light weight, the true firs, hemlocks, and spruces require less painting maintenance than western larch.

The larch-fir mixture does not have so wide a range of usefulness as western larch because of the higher percentage of nondurable sapwood in the Douglas fir ("Inland Empire" type). Boards with a high percentage of sapwood should not be used where there is a decay hazard. If the difference in the hardness of the two species in the larch-fir mixture is objectionable (p. 24), the Douglas fir can be separated from western larch.

DIMENSION

Dimension is used for many purposes in building construction. Joists, studding, stringers, planks, rafters, scaffolding, sills, and bracing are some of the more important uses of dimension. Each of these uses requires a different combination of properties. There are few softwoods that meet the requirements of all the uses of dimension as well as western larch. As a result over half the cut of western larch and Douglas fir ("Inland Empire" type) go into dimension.

Over 95 per cent of the larch-fir dimension is of the No. 1 Dimension and Timber grade. A small amount of No. 2 Dimension is manufactured, and practically no No. 3. The bulk of the larch-fir dimension is nominally 2 inches thick and from 4 to 12 inches wide. (Fig. 24.) Stock 3 and 4 inches thick and some stock wider than 12 inches, however, is available. Sixteen feet is the usual length; however, shorter lengths are available as a result of trimming. Long lengths of 20 feet and over are not readily available, although there is a demand for such lengths in some cities and they can be produced from western larch trees.

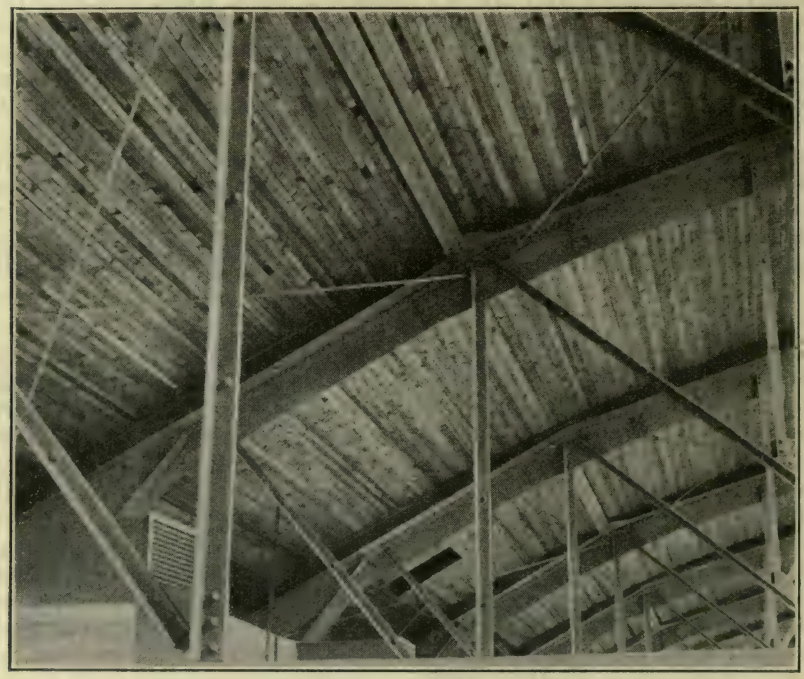


FIGURE 24.—Gymnasium roof made of western larch 2 by 4-inch dimension on edge. The strength and nail-holding power of western larch well adapt it to this type of use

High nail-holding power is a common requirement in practically all uses of dimension. It is desired to hold sheathing, flooring, or other covering to the framing. Light weight and ease of working, which facilitate fabrication, are also universally desirable properties in all uses of dimension. Stiffness is the most important strength property in many items of dimension, especially in 2-inch stock. In stock thicker than 2 inches bending strength usually replaces stiffness as the most important strength property. Comparison of western larch with other species in any of the foregoing properties, except ease of working, can be made from Table 4. Such a comparison justifies the previously made statement that few softwoods meet all of the use requirements of dimension as well as western larch.

The larch-fir mixture does not have so favorable a combination of properties for dimension as western larch. This is because the

Douglas fir ("Inland Empire" type) in the mixture has a lower nail holding power and a lower bending strength than the western larch. The stiffness of two species in the mixture is practically the same. The larch-fir dimension consists of about three parts of western larch to two parts of Douglas fir ("Inland Empire" type). (Table 8.)

JOISTS AND STUDS

From a utility standpoint stiffness and nail-holding power are the important properties in joists and studs. Stiffness is desired of joists and studs in house construction because the amount of deflection that can occur without damage to the plaster is small. Nail-holding power is desired to hold flooring, siding, sheathing, and lath in place. In stiffness and nail-holding power, western larch

FIGURE 25.—Framing for dwellings is one of the principal uses for western larch. It is used for studding, joists, rafters, and sills

ranks high among the softwoods. Comparisons of the stiffness and nail-holding power of western larch with that of other species are made in Figures 15 and 19. Figure 25 shows western larch joists and studs in the framework of a dwelling.

In heavy joists over 2 inches in thickness, bending strength is usually of greater importance than stiffness, and decay resistance is often an added requirement. Heavy joists are used in the construction of warehouses, mills, and similar structures. They must carry heavy loads, there is no plaster to crack, and occasionally, as in textile mills, conditions are favorable for decay. The load-carrying capacity of heavy joists should be judged by the discussion under Structural Timbers (p. 71). Western larch meets the requirements of heavy construction even better than it does those of small houses or light construction. The bending strength of western larch (fig. 11) compares more favorably with that of other species than does its stiffness (fig. 15). The moderate decay resistance of western larch is also an asset.

Western larch joists and studs are heavy and hard, and consequently are not so easy to fabricate as those of the lighter and softer species shown in Figures 8 and 13. The importance of weight and

hardness in joists and studs lies in their influence on construction costs. Heavy joists and studs are harder and slower to handle and place than light ones. Hardness increases the difficulty in cutting, sawing, and nailing.

STRINGERS

Bending strength combined with decay resistance is the combination of properties desired in stringers. Bending strength is desired because stringers are primarily load-carrying members, and decay resistance is desired because they are often used under conditions favorable to decay. The requirements of stringers are, therefore, similar to those for heavy joists except that decay is more often an important requirement.

Stringers are structural timbers, although they may be and often are of dimension size, that is, under 5 inches thick. Like all structural members, the strength of stringers is dependent more on the size, number, and location of the defects than upon the strength of the clear wood. The safe working values in Table 16 should be used in preference to values for clear wood in comparing the strength of western larch stringers with those of other species. Such a comparison is based on comparable grades and consequently takes into consideration the influence of defects. A high percentage of western larch No. 1 Dimension and Timbers should class as select under basic requirements for structural material of the American lumber standards (*28*) because of the characteristically small size of the knots in western larch.

PLANKING

The value of western larch as planking lies largely in the combination of properties and characteristics which make it a good general utility wood. The use requirements of planking vary widely. (Fig. 26.) The most important requirement may be resistance to wear, resistance to decay, or load-carrying capacity. Some uses combine all three of these requirements. Western larch is especially adapted for use as planking, for it combines high hardness and bending strength with moderate decay resistance. In addition, the uniformly narrow annual rings in western larch result in a more even texture than is generally found in woods with alternate bands of hard and soft wood. A comparison of these properties and characteristics of western larch with those of other softwoods shows that while a few species rank higher in some one of the desired properties, none of the species rank higher in all.

The larch-fir mixture is not so desirable for use as planking as western larch. The difference in the hardness and texture between western larch and Douglas fir ("Inland Empire" type) when used in mixture may cause uneven wear, which is undesirable. In addition, higher working stresses are recommended for use with western larch than for the larch-fir mixture. Where the most important property desired is load-carrying capacity, the working stresses recommended in Table 16 for Douglas fir (Rocky Mountain type) should be used for the mixture. In computing load-carrying capacity the safe working values recommended in Table 16 are applicable to dimension used flatwise as well as on edge. Where planking is to be subjected to heavy wear western larch should be specified or

the Douglas fir should be sorted from the larch-fir mixture and used as a unit, preferably where wear and stresses are lightest. Such a separation of the larch-fir mixture will reduce the tendency of adjacent planks to wear unevenly. In addition the side from nearest the bark, that is, the sap side of flat-grained plank of both species, should be placed up to reduce the tendency to sliver.

RAFTERS

The primary requirements of rafters are bending strength and nail-holding power. Bending strength is required to carry loads imposed by roofing, snow, wind, and live loads; nail-holding power is required

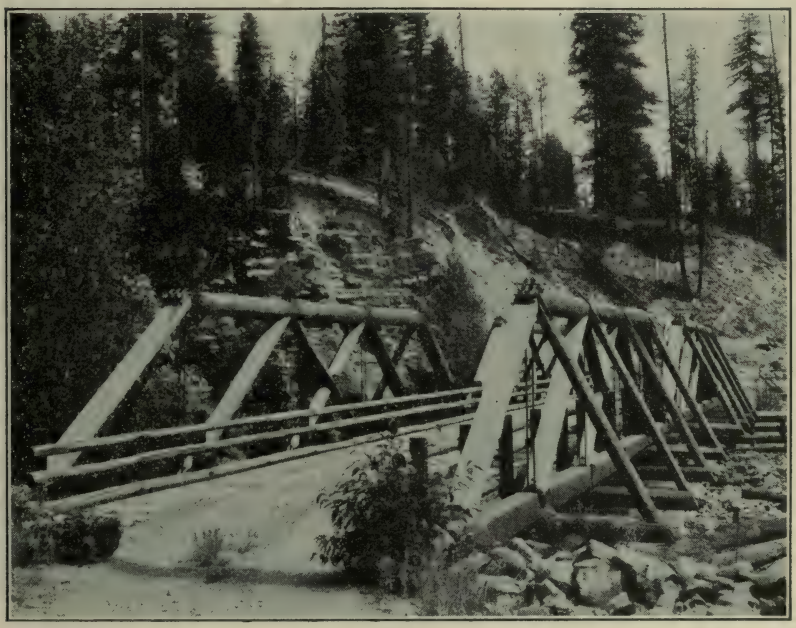


FIGURE 26.—A highway bridge made of round western larch timbers. Western larch in round form has a high percentage of heartwood

to hold roofing boards in place. (Fig. 27.) Light-weight and ease of working are desired to facilitate construction.

The bending strength and nail-holding power of western larch, rather than its ease of working, commend it for use as rafters. The bending strength of western larch rafters is due more to the characteristically small size of its knots than to the high bending strength of clear wood. Western larch knots, though numerous, average smaller in size than those of any species commonly used for rafters. The nail-holding power of western larch combined with retention of nail-holding power under varying moisture conditions indicates that it will hold roofing in place as well as or better than any of the woods now in common use. In ease of working it is very similar to Douglas fir (coast type) and southern yellow pine, but it is harder to work and heavier to handle than the spruces, true firs, and hemlocks.

The larch-fir mixture does not differ greatly from pure larch in suitability for rafters. The load-carrying capacity of the Douglas fir ("Inland Empire" type) in the larch-fir combination will be slightly lower than that of western larch due to the lower bending strength of the clear wood and the slightly larger average size of the knots. The Douglas fir ("Inland Empire" type) rafters will probably not hold roofing boards quite so well, but will be easier to work and lighter to handle.

SILLS

Decay resistance or nail-holding power or both are usually primary requirements of sills. In small-house construction sills are usually protected from moisture. Their principal function is to hold in place members which are nailed to them. Sills, however, are often used in contact with the ground or under conditions favorable to decay. The

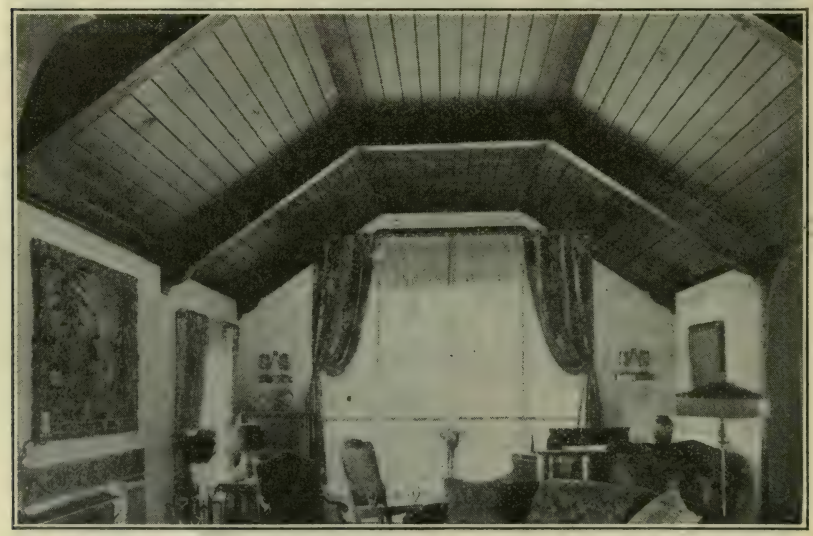


FIGURE 27.—Heavy rafters of western larch. The rafters are hand adzed

moderate decay resistance and nail-holding power of western larch are favorable to its use for sills. If the decay hazard is high, as when parts are in contact with the ground, the sills should be treated. A comparison of the properties of western larch with those of other species shows that none of the species commonly used for this purpose have a better combination of these properties.

SCAFFOLDING AND BRACING

The properties of western larch to be compared with those of other species in order to determine its value for scaffolding and bracing are stiffness, strength both in bending and compression, nail-holding power, and ease of working and handling. The strength, stiffness, and nail-holding power of western larch commend it for work where heavy loads are to be supported. The hardness and weight of western larch are a disadvantage in work where loads are light and speed of erection is important.

STRUCTURAL TIMBERS

The value of western larch for structural timbers depends primarily upon its strength in large sizes and upon its moderate decay resistance. The strength of structural timbers, however, depends more on the defects, such as knots, decay, shakes, and checks, that are present in the timbers than upon the inherent strength of the clear wood in them. Comparison of western larch structural timbers with those of other species must therefore be based on comparable grades. At present the commercial structural grades of other species are not comparable with the dimension and timber grades of western larch. The only comparable grades on which to base a comparison of the strength of western larch timbers with those of other woods are the American lumber standards (*28*) basic provisions for structural material. The working stresses recommended in Table 16 are for grades meeting these basic provisions and therefore can be used for comparing western larch structural timbers with those of other species. Such a comparison shows that the values recommended for fiber stress in bending and modulus of elasticity for western larch are lower than those recommended for a number of the softwoods. The values recommended for shear, compression parallel and perpendicular to the grain, however, do not differ greatly from those recommended for the heavier softwoods. The comparatively low values recommended for western larch for fiber stress in bending are due to the results of tests of the wood in structural sizes (*11*).

The determination of values from Table 16 on which to base design in a structure is a highly technical problem. It will vary in structures with the use requirements and conditions, and should be left to an engineer or an architect.

The character of the knots in western larch is favorable to the production of structural timbers. Their characteristically small size enables a high percentage of the timbers to meet the knot specifications of the higher strength grades. The predominance of encased over intergrown knots is an advantage, for encased knots are less injurious to the strength than intergrown knots of the same size because the grain distortion around them is less.

Many untreated structural timbers are used where conditions are more or less favorable to decay. The combination of moderate decay resistance and strength in western larch is such that the species can meet the requirements where untreated timbers are not essential. (Fig. 28.)

INTERIOR TRIM

The most desirable properties and characteristics of western larch for interior trim are its figure, color, hardness, and slow response to changing moisture conditions. Its alternate bands of hard and soft wood result in a pronounced figure that is especially adapted to natural finishes. Stains blend well with its natural reddish brown color, and hardness reduces the tendency to wear, mar, or dent.

Western larch interior trim is commonly used with natural or stained finishes rather than with paint finishes. (Fig. 22.) Natural and stain finishes bring out the figure. On the other hand, the tendency of the figure to show through and the tendency of the summerwood bands to rise slightly are objectionable in light-colored paint

and enamel finishes. Lighter-colored softwoods with less pronounced summer-wood bands are therefore generally preferred for enamel and highly decorative paint finishes.

The principal items of western larch interior trim are ceiling, partition, and wainscoting, all of which are manufactured in a variety of patterns and go largely into such uses as porches, pavilions,

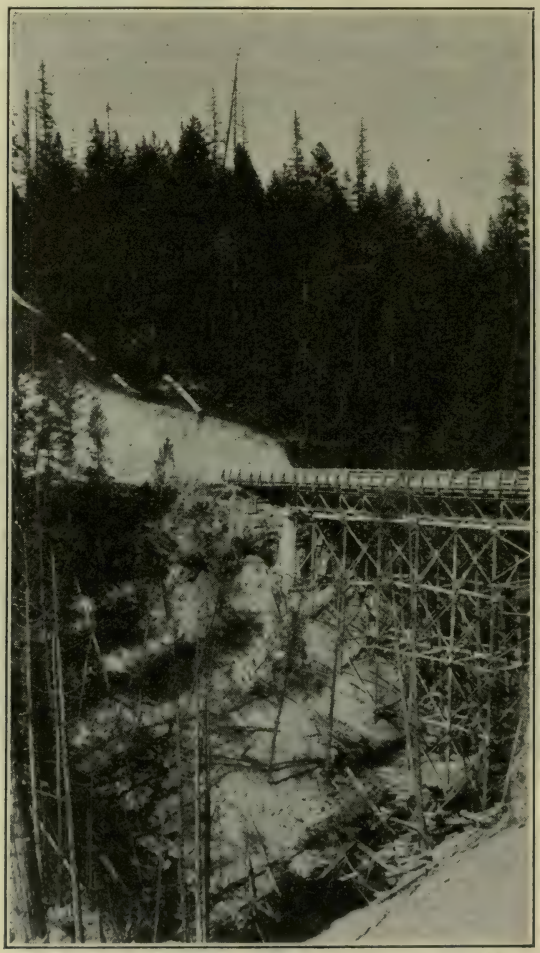
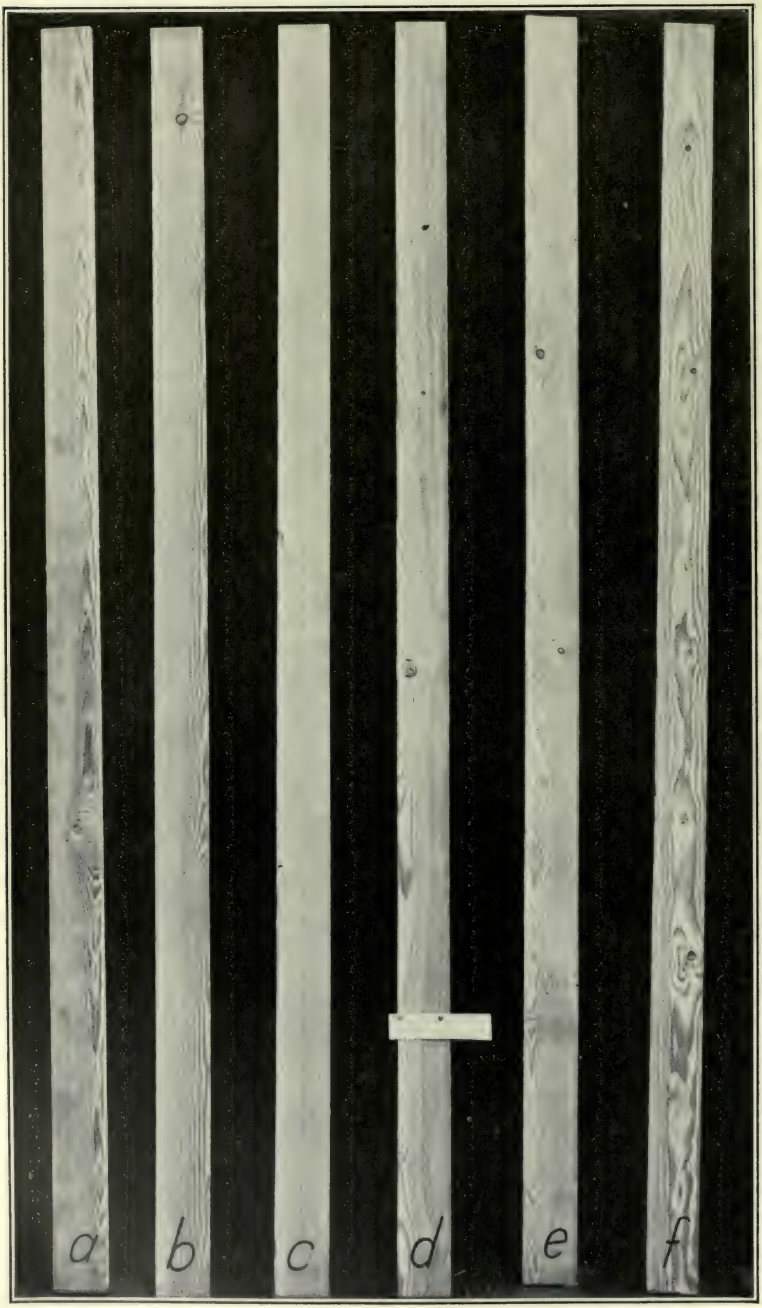


FIGURE 28.—A highway bridge of western larch. The strength and moderate decay resistance of western larch make it a desirable species for bridge timbers

and beach houses, where there is some exposure to the elements. In such uses the moderate decay resistance, adaptability to natural and stain finishes, and hardness of western larch form a desirable combination of properties and characteristics. Other items of western larch interior trim are molding, trim balusters, colonnades, newel posts, and stair treads. Figure is also desired for natural and stain finishes, and hardness for resistance to wear, denting, and marring. Decay resistance, except under exceptional conditions, is of no prac-

M12140F

Western larch finish of C grade has a high percentage of practically clear pieces, such as *a*, *b*, and *c*, and contains only small defects such as are shown in *d*, *e*, and *f*. The beauty of figure in flat grain *b* and the uniformity of figure in edge grain material *f* are shown



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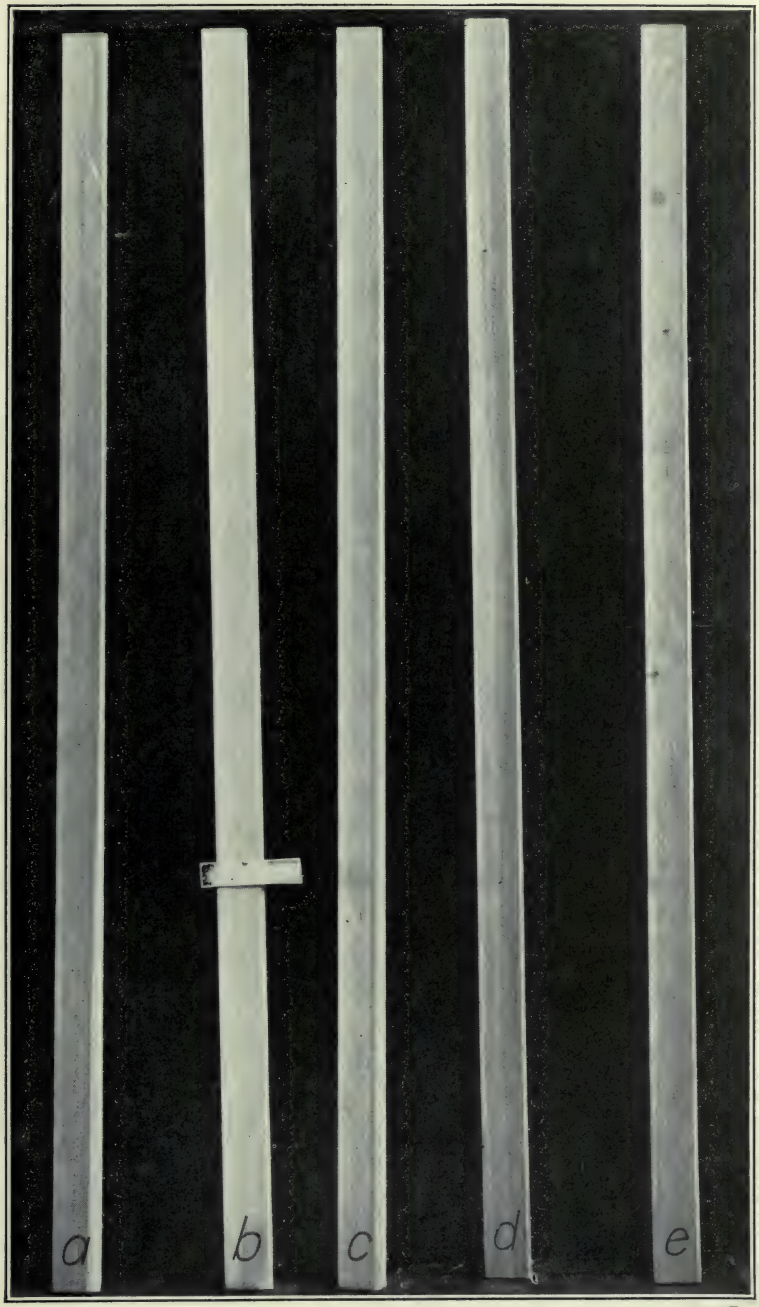
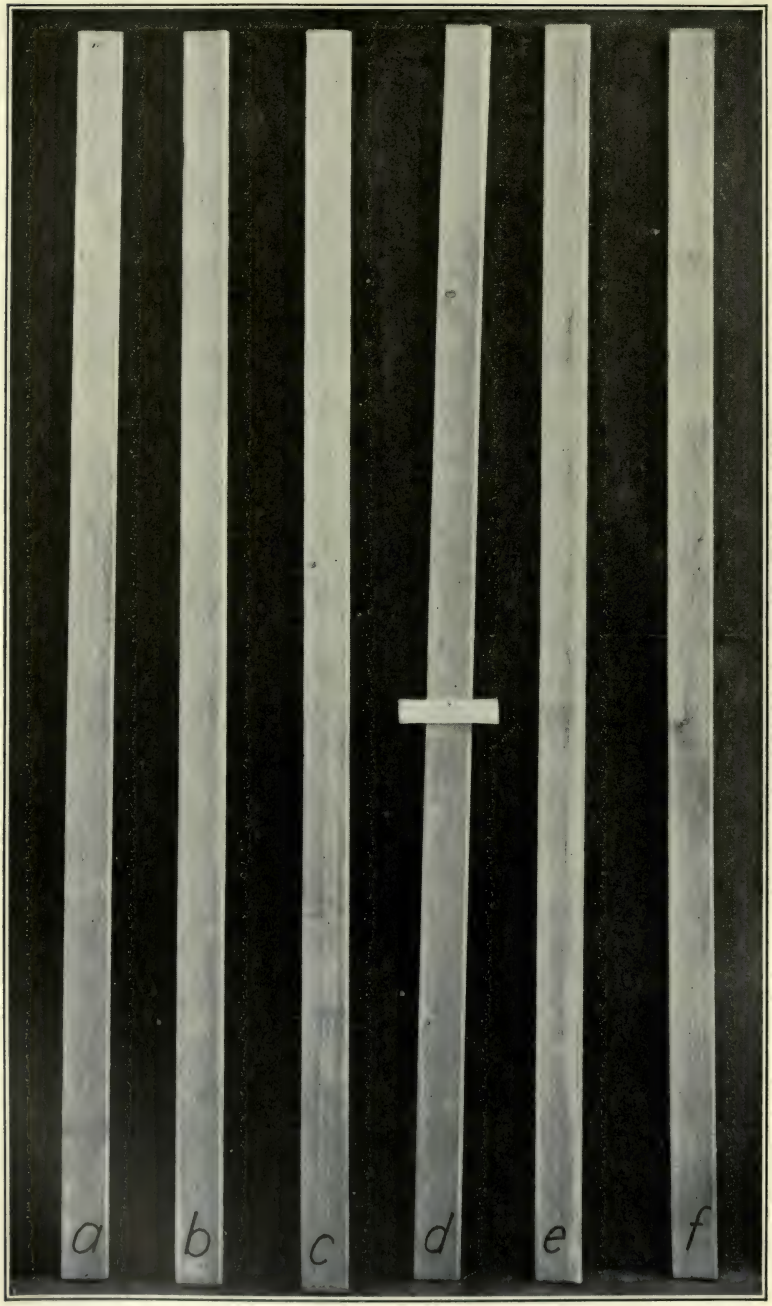
Western larch finish of D grade surfaced on two sides. The waste in converting the grade into clear material by cutting is small



M12142F

Center-matched, vertical-grained western larch flooring of C and better grade. The grade has a high percentage of practically clear boards, such as *a*, *b*, and *c*. Small black knots of about one-fourth inch in diameter, such as shown in *d* and *e*, are in about one-third of the boards. The narrow annual rings account for the uniform appearance and "wire-grain" figure that is typical of western larch vertical-grained flooring



M12141F

Center-matched, vertical-grained western larch flooring of the D grade. A practically clear floor can be obtained from this grade with small waste from cutting. About one-third of the pieces have a face free of knots, such as *a* and *b*. They are in the grade because of poor backs, checks, or torn grain. Other pieces, such as *c*, *d*, and *f* can be cut to give practically two clear pieces. Occasionally pieces will have small pitch pockets, such as shown in *e*

tical importance in interior trim. Figure 29 shows western larch beams, molding, casing, base, and doors used as an interior trim.

Western larch interior finish is manufactured principally in two grades, C and Better, and D. The general appearance of these two grades, both as to figure and defects, is shown in Plates 11 and 12. The C grade permits only small defects and has a high percentage of clear material. In fact, a single serious defect is sufficient to cause the rejection of a piece. The D grade is made up of pieces with one serious defect that may be cut out, thus leaving two practically clear pieces of boards having a C or Better face but a back that will not meet the requirements of the D grade, and of boards with a number of small minor defects.

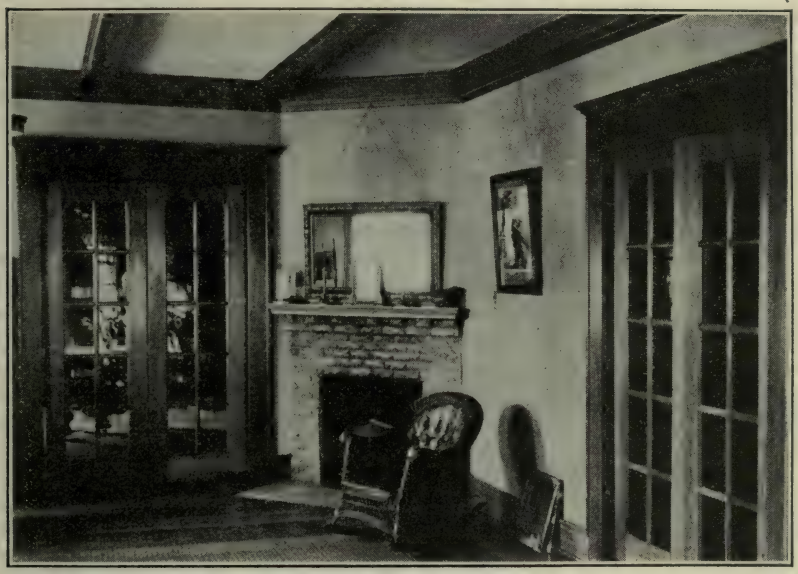


FIGURE 29.—Western larch interior trim in beams, molding, casing, base, and doors. The adaptability of western larch to natural and stain finishes and its hardness are a desirable combination of properties for this use

Only about 3 per cent of the western larch finish is wider than 6 inches. Only about 1 per cent of the finish is thicker than 1 inch. Most of the finish is 16 feet long, although there is a demand in some sections and in the larger cities for 14-foot material because of the high proportion of porches which are 7 feet wide.

FLOORING

The combination of properties possessed by western larch makes it suitable for use in practically all types of flooring. The wood has hardness for resistance to denting, marring, and wear; uniform narrow ring growth for uniformity of appearance and wear; slow response to moisture changes for reduction of shrinking and swelling; high bending strength and stiffness for supporting heavy loads; a moderate resistance to fungous attack; and small, tight knots with correspondingly small effect on strength. Western larch shrinks

more than most softwoods used for flooring (fig. 17), but less than the hardwoods which furnish some of our finest flooring. Ease of working and painting characteristics of western larch also are not so good as those of a number of lighter, more uniform-textured softwoods.

Western larch is manufactured in a variety of types, grades, and sizes to meet demands of different types of flooring. The principal types are edge grain, flat grain, surfaced two sides, center matched, and jointed (square edge). The select grade is confined to narrow widths of 3, 4, and 6 inches and to thickness of 1 and 1¼ inches. Western larch select grades are largely edge grain. The common grades are largely 1-inch stock of mixed edge and flat grain, and are available in widths of 4 to 10 inches. The flat-grained stock predominates in the common grades.

Western larch is probably best adapted to the manufacture of high quality, narrow, end and side matched, edge-grained flooring of the type used in residences, offices, gymnasiums, and ballrooms. This type of softwood flooring is carefully selected for uniformity and narrowness of annual-ring growth. Narrow, uniform growth rings are the outstanding growth characteristic of western larch. A higher percentage of the cut of western larch meets the requirements for narrow ring growth than is the case with any of the other softwoods commonly used for flooring of this type. In addition, the narrow sapwood ring makes for a high percentage of all heartwood pieces. Sapwood is objectionable because it contrasts in color with the heartwood. Western larch has a high resistance to denting and marring because of its hardness. The edge-grained flooring of C and Better and D grades of western larch illustrated in Plates 13 and 14 show the "wire-grain" figure resulting from very narrow uniform annual rings.

The bending strength, stiffness, hardness, small tight knots, and uniform ring growth of western larch adapt it to heavy flooring for factories, mills, and grain elevators. Its bending strength enables it to support heavy loads, and the deflection under such loads is small because of the stiffness of the wood. Injury to strength from the characteristic small tight knots is small, and a good wearing surface is provided by the combination of hardness and uniform narrow annual rings, especially in edge-grained material. The wood is well adapted to bridge, platform, and similar types of heavy flooring, because it combines moderate decay resistance with the other properties that adapt it to heavy-service requirements.

One of the popular uses for western larch at present is for flooring in such structures as porches, pavilions, balconies, and beach houses. Jointed or square-edged flooring also goes into this type of use. Out-of-door flooring is subjected to some decay hazard, the wearing requirements are similar to those in houses or offices, and the wood may receive either a paint or natural finish. Edge-grained material is preferred and is superior to flat-grained material for out-of-door flooring. The larch-fir mixture is not so satisfactory for flooring as western larch, chiefly because of the higher percentage of sapwood, the wider and less uniform growth rings, and the lower degree of hardness of the Douglas fir ("Inland Empire" type).

The common grades of western larch make an excellent barn flooring. The knots, while more numerous, are smaller than in any of the softwoods used for this purpose. The average size of knot in the No. 3 Common grade of western larch is only one-half inch in diameter. In addition the knots in western larch are generally tight; only about 1 knot in 30 in No. 3 Common is loose or missing. Unsound and decayed knots are rare in the western larch grades higher than No. 4 Common, occurring in only about 1 board in 30. The small knots combined with the bending strength and the stiffness of the wood enable western larch flooring to carry the heavy loads it is sometimes called upon to support, the hardness provides resistance to wear, and the moderate decay resistance of the wood makes it desirable.

EXTERIOR TRIM

Western larch is best adapted to those items of exterior trim that are subjected to some decay hazard. While much exterior trim is used where conditions are unfavorable to decay action, some resistance to decay is necessary or desirable in such items as drip boards, garage doors, porch columns, and porch steps. Sometimes these items are so placed as to reduce or eliminate the decay hazard; however, knowledge that decay resistance will not be required is seldom available in advance of use. The more decay resistant a species is the better it is adapted to these items, other things being equal. On the other hand, items such as trim, moldings, and siding are seldom subjected to conditions favorable to decay. Where there is no decay hazard the better painting qualities and greater ease of working of the lighter-colored, more uniform-textured, lighter-weight, and softer woods will usually outweigh the greater strength and moderate decay resistance of western larch.

Western larch exterior trim should be painted as soon as practical after it is placed in service. The wood will start to weather check in a short time if exposed unpainted, especially if it is not thoroughly dried. Also, a good protective paint coating should be maintained on western larch, since the wood checks and the grain loosens or rises more quickly and more than on lighter, more uniform-textured woods.

Most items of western larch exterior trim are manufactured in both the select and common grades. The bulk of the production in all items, however, is of C and Better and D grades. A few items, such as casings, window and door frames, wainscoting, and screens, are produced only in the select grades. The finish shown in Plates 12 and 13 is as adaptable to exterior as to interior use.

SIDING

Western larch is produced in drop, bevel, and rustic siding. In addition, ship-lap and surfaced two sides and center-matched boards are also used for siding. The first three types are produced only in 4 and 6 inch widths of the select grades. The ship-lap and surfaced two sides and center-matched boards are obtainable in any grade and in widths up to 12 inches. The bulk of the production, however, is of common grades and in widths of from 4 to 8 inches.

Western larch siding is very similar to that of Douglas fir (coast type) in appearance, painting characteristics, decay resistance, and strength. Its painting characteristics are not so good as those of the more uniform-textured, softer, and lighter woods. This, however, can be compensated for to a large extent by confining the manufacture of western larch siding to edge-grained material. Edge-grained western larch siding will require repainting in approximately the same time as flat-grained siding of softer, lighter, and more uniform-textured species. Edge-grained material of such species, however, will not require repainting so soon as edge-grained western larch. The difference in time before repainting is required for the protection of the wood depends on the species. The properties and the characteristics of western larch that are desirable in siding are moderate decay resistance, the small, tight character of its knots, the small amount of sapwood, and the slow response to moisture changes. Sometimes one and sometimes a combination of the above properties and characteristics account for the use of the bulk of the western larch siding for barns, factories, grain elevators, houses, silos, and warehouses.

PORCH COLUMNS

The principal cause of failure of columns used for exterior decoration of houses is decay. The methods commonly used in construction permit the collection of moisture around the ends of the columns and thus establish a high decay hazard. Western larch porch columns, while moderately decay resistant, should be treated with a preservative. Columns must be kept well painted to prevent checking; the paint, however, also prevents any moisture that may be absorbed at the ends of the columns from drying out rapidly and therefore may make conditions favorable for decay. Columns constructed of nondurable woods or columns which contain sapwood rot out in a comparatively short time. The small percentage of sapwood in western larch makes it easy to select all heartwood pieces for columns. Care should be exercised to prevent, in so far as possible, the absorption of moisture through the ends of columns, even with a decay-resistant wood.

DOORS

The same properties and characteristics which have made the Douglas fir (coast type) doors so popular also make western larch a good wood for doors. Western larch has a pronounced figure with natural and stain finishes. It also has a high degree of hardness, which tends to reduce the denting and marking from knocks and blows. The high heartwood content of western larch makes it easy to obtain the desired uniformity of color. All heartwood is also important in some exterior and in many garage doors because of the low decay resistance of sapwood. High nail or screw holding power is also desirable in all doors for fastening hinges. It is especially necessary in garage doors because of their size and weight. The swelling and shrinking with changing atmospheric conditions, which are objectionable in all doors, are reduced by the slow response of western larch to moisture changes. This property, however, is largely offset by the high shrinkage of the wood. Western larch

doors that are exposed to the weather must be kept well painted or protected by a good natural finish if they are to prove satisfactory. In this respect they will require more maintenance than doors made from lighter, more uniform-textured woods. Generally, the properties of western larch adapt the species to doors subject to some decay hazard, doors with pronounced figured finishes, large heavy doors, and doors subject to hard usage from knocks and blows. While it is adaptable and can be used for light doors finished with paint or enamel, the lighter and more uniform-textured woods meet the requirements for such doors better, provided the decay hazard is low.

SASH AND FRAMES

Sash and frames for doors and windows are quite generally made from softer, more easily worked woods with more sapwood than western larch. So far practically no limitation has been put on the amount of sapwood admissible in sash and frames. Some demand, however, has arisen for more decay-resistant and stronger sash and frames. This demand has developed in factories, hotels, and greenhouses, and other buildings which have a decay hazard or which are using exceptionally large and heavy windows, where replacements are expensive. Western larch, because of its strength, hardness, and moderate decay resistance, meets these requirements about as Douglas fir (coast type) does. Edge-grained western larch is much better adapted to use in sash and frames than is flat-grained material.

STEPS

Resistance to decay and wear are two important requirements of stepping used out of doors. The hardness and moderate decay resistance of western larch adapt it for stepping. In addition, its narrow and uniform annual rings result in uniform wear, which is very desirable in stepping. Edge-grained western larch stepping is much superior to flat-grained stepping, because it takes and holds paint better, wears more uniformly, and reduces the chance of the grain loosening and creating a tripping hazard. Poor design, wood in contact with the soil, joints that collect and hold moisture, and lack of ventilation, rather than lack of decay resistance of wood, are responsible for much of the replacement necessary with stepping. Satisfactory results can not be expected from western larch stepping, even though it is decay resistant, if the design is poor.

The requirements of interior stepping differ considerably from those of exterior stepping. In interior use appearance is more important, wear is not so severe, protection against wear is better, and the decay hazard is practically negligible. Western larch stepping for interior use, therefore, does not have the advantages over stepping of soft, lightweight, nondurable woods that it possesses in exterior use. Stepping for interior use is selected in most cases to match other trim. Edge-grained western larch furnishes the popular "wire-grain" figure, and flat-grained material furnishes the pronounced figure. With natural finishes both edge-grained and flat-grained stepping result in a comparatively dark trim. The desirability of western larch stepping for interior use depends largely upon personal preference for color and figure.

INDUSTRIAL USES

It is impractical to discuss all of the industrial uses of western larch. They are too numerous and the requirements vary too widely, depending on the design and quality of the finished article it is desired to produce. (Fig. 30.) A few of the more important industrial uses are discussed to show how in the absence of experience or special tests the information on properties and characteristics can be used to determine the suitability of western larch. The consumer, with more complete knowledge of his requirements and local market prices can come to a more definite conclusion as to the suitability of western larch for his purpose than is possible in this bulletin. Here it is only possible to compare general requirements with properties and characteristics of western larch and show the adaptability of the wood to the use without deciding whether it or another wood should be used. Determining the most desirable species to use involves comparisons of price as well as of properties and characteristics.

MINE TIMBERS

Considerable western larch is used for mine timbers. A number of the mills, especially small ones, make a specialty of mine timbers and ties. Some of them run practically the entire cut to these products. The large mining operations in the "Inland Empire" furnish a ready market for western larch mine timbers. Because of its combination of strength, moderate decay resistance, high heartwood content, and small knots, western larch mine timbers are better than those of any other species grown in the "Inland Empire." As manufactured at present, sawed western larch mine timbers are probably equal to those of any softwoods commonly used for this purpose. Softwoods whose clear wood is stronger than that of western larch have larger and more injurious knots. When the quality of the clear wood and defects present in the various species are considered, therefore, western larch mine timbers will compare favorably with those of any of our other native softwoods.

Western larch in round form is especially adapted to the requirements of mine timbers because of its narrow sapwood. The high heartwood content results in a higher percentage of decay-resistant wood than is commonly found in any softwood species of equal or higher strength. An increase in the production of western larch mine timbers is not desirable from the standpoint of good utilization, because at present too much of the D product of the log is going into mine timbers. Good utilization requires that such high-quality material be marketed for uses with more exacting requirements.

CROSSTIES

About 10 per cent of the total western larch cut annually goes into crossties. It is estimated that about 4 per cent is in the form of hewed crossties and 6 per cent in the form of sawed crossties. Small circular mills, which produce only crossties and other rough products (fig. 31) increase the percentage of sawed crossties from the 1.1 per cent reported by association mills. (Table 9.)

The suitability of western larch for crossties is, so far as mechanical properties are concerned, shown by composite strength figures

FIGURE 30.—A logging chute constructed of larch-fir. The high degree of hardness and decay resistance of western larch adapt it to such outdoor uses where it is in contact with the ground and subject to exceptional loads and heavy wear

for softwoods (*14*) to be exceeded only by southern yellow pine, alligator juniper, and Pacific yew. The high rating of western larch is due to its bending strength which enables it to resist center bending, its nail-holding power which furnishes resistance to spike pulling, and its hardness which enables it to resist rail and plate wear.

The average life of untreated western larch ties in a mainline test track in Montana subjected to heavy traffic was seven and one-half years. Douglas fir ("Inland Empire" type) in the same test track had about the same average life. The life of ties, however, varies so widely with service conditions that the average life is indicative only and not necessarily a measure of the life that will be obtained in any specific tie. The high heartwood content and the moderate decay

FIGURE 31.—Manufacturing western larch crossties. Many circular mills, such as shown here, confine their output to crossties and mine timbers, to which uses western larch is well adapted

resistance of western larch are important assets when ties are to be used untreated. On the other hand, in ties that are to be treated with preservatives, the high heartwood content is not desirable, for sapwood is much easier to treat than heartwood.

Western larch is not an easy wood to treat with preservatives. However, with the aid of incision, a number of commercial plants now successfully treat the species.

TANKS

Decay resistance is usually the most important requirement of wood for tanks. Either tight-knotted material or clear wood is required, and the wood should not be easily penetrated by liquids. Water-soluble extractives are objectionable for some uses to which tanks are put.

The small amount of sapwood in western larch and the inherent decay resistance of the heartwood make western larch suitable for

tanks of moderate life requirements. Sapwood, when used in tanks, causes high maintenance charges and unsatisfactory service, for it is low in decay resistance. The sapwood is easily excluded from western larch tank material and involves less waste with western larch than with most woods used for tanks. The larch-fir mixture meets the requirements for tanks about as well as western larch except that a somewhat higher wastage occurs in eliminating the sapwood. Neither western larch nor Douglas fir ("Inland Empire" type) is easily penetrated by moisture, but the Douglas fir is more difficult to penetrate than western larch.

No. 1 and No. 2 Common are the grades of larch-fir commonly used for tanks. The tightness and small character of the knots in western larch and Douglas fir ("Inland Empire" type) enable such a low grade to be used with a small amount of cutting, the Douglas fir requiring more cutting than the western larch.

In western larch the galactan (p. 43), which is soluble in water, may prove objectionable for some tanks. Trouble from this source, however, can usually be prevented by thorough soaking before or after construction.

SILOS

Wood in silos is subjected to severe conditions. It is alternately wet and dry and therefore subjected to conditions favorable to decay and to swelling and shrinking. The pressure exerted by silage subjects the wood to some stress. Western larch has the desired strength for silos and can be used untreated, but will give better service if treated with a wood preservative.

Like all woods, western larch is a good thermal insulator, furnishing protection against the silage freezing and holding the heat in the silo during the fermentation stage. In this respect, western larch is better than the heavier woods, but not so good as the lighter woods. Generally, however, tightness of construction is more important in obtaining good thermal insulation than the kind of wood used.

Good silage can only be secured by having an air-tight wall. The wood in a silo must therefore stay in place well. Western larch is straight grained, and consequently has small tendency to warp and twist and thus permit leakage of air. On the other hand, its shrinkage is high, and in western larch silos therefore careful attention should be paid to hoop and anchor cables. The resistance of western larch to the penetration of liquids is an advantage when the wood is used in silos.

The small number of loose knots, knot holes, unsound and decayed knots in western larch favor its use in silos. Knot holes are objectionable in silos in that they may permit leakage of air, and boards or staves containing knot holes should therefore be cut or culled. While the black color of many of the knots in western larch is sometimes objectionable from an appearance point of view, they do not injure the serviceability of the silo when they are tight.

Silos constructed of western larch should be painted as soon after erection as possible to prevent weather checking. Western larch silos require somewhat more painting maintenance than lighter woods without pronounced summer-wood bands.

No sapwood should be permitted in untreated silo staves or siding because the sapwood of all species has low decay resistance. The narrow sapwood ring of western larch makes it easy for the species to meet the sapwood requirements for silos. One manufacturer reports changing from a more decay-resistant species to western larch because western larch has less sapwood. The change materially reduced maintenance charges resulting from his guarantee even though the larch required more painting. This manufacturer has used a special drop siding of western larch on thousands of silos.

The properties and characteristics of western larch are as a whole admirably adapted to the requirements of silos. To obtain full advantages of the properties of western larch, however, requires somewhat more care and attention than is necessary with the weaker and lighter woods with less pronounced summer-wood bands. Special grades for silo staves would aid in marketing western larch in this field. Such grades, if drawn to take advantage of the lack of sapwood and the small, tight-knotted characteristic of the species, would provide a high-quality silo material.

FREIGHT-CAR CONSTRUCTION

Decay is responsible for more replacements in freight cars than all other causes combined. A study of 265,666 individual freight-car parts showed that 82.3 per cent failed because of decay (*4*). In items, such as roofing, decking, grain strips, and running boards, replacements were due almost entirely to decay. The value of the decay resistance of western larch is obvious when the species is used in freight-car construction.

Strength and hardness are required in freight cars to withstand the shocks and to resist the hard usage that car material receives. Western larch ranks high in both strength and hardness. Only the strongest and hardest of the softwoods are equal to western larch in this respect. (Figs. 11 and 13.)

The use of western larch for car lining, siding, decking, and roofing has been handicapped by the fact that it has not been readily available in the desired sizes and quantities. Most of the western railroads use 1¾-inch stock for decking and $\frac{13}{16}$-inch stock for siding, lining, and roofing. Western larch is not readily available in these thicknesses except to railroads owning their own mills. Railroads purchasing western larch have had to take 1⅝-inch stock for decking and $\frac{25}{32}$-inch or ¾-inch stock for roofing and lining. Several car builders and repair shops report satisfactory service from No. 3 Common western larch for longitudinal roofing under a Douglas fir (coast type) finished lateral roof. Engineers report the successful use of western larch in refrigerator cars for lining, for strips to keep meat away from walls, and for temporary floor racks in fruit cars. The moderate decay resistance, hardness, and small, tight knots of the species are largely responsible for satisfactory results being obtained in spite of the fact that the material is thinner than that commonly used.

The combination of strength, decay resistance, nail-holding power, and retention of nail-holding power should enable western

larch to render good service as car framing. No. 1 and No. 2 Dimension are the grades commonly used for frames, sills, and posts. Moderate decay resistance, combined with high heartwood content, permits the use of western larch untreated timbers; the high bending strength combined with small knots provide for the required strength; the nail-holding power and the retention of nail-holding power enable timbers to hold siding, roofing, and lining under the varying atmospheric conditions that cars encounter in moving from one part of the country to another.

Generally the properties and characteristics of western larch are favorable to its use in freight cars, but the sizes in which it is most readily available are unfavorable to its use for certain items. If western larch is to be more extensively used for siding, lining, roofing, or decking, either the manufacturers must make provision to cut the special thicknesses that railroad-car builders believe to be necessary, or some conclusive data must be obtained to show that the sizes available in western larch are adequate to meet the requirements of some or all of these items.

CROSS ARMS

Very little western larch is used for cross arms. Douglas fir (coast type) and southern yellow pine furnish the bulk of wood for this purpose. One company alone used over a million cross arms of these two species. The heartwood of western larch, being very similar to that of Douglas fir of coast type in its strength properties and decay resistance, would be expected to meet cross-arm requirements about as that species does. The Douglas fir would have an advantage due to its greater stiffness, and western larch an advantage due to its greater hardness. Southern yellow pine would have an advantage in strength and stiffness but a smaller advantage in hardness. On the other hand, the growth and defect characteristics of western larch are better adapted to the rigid specifications of the large users of cross arms than are those of either Douglas fir or southern pine. The limitations on the size of knots in cross arms are rigid and definite. The average knot in western larch is smaller than that in Douglas fir and only about half the size of the average knot in southern pine. The percentage of the objectionable loose, missing, and unsound knots is also lower in western larch than in Douglas fir and southern yellow pine. Pitch pockets occur only about one-third as often in the western larch as in the other two species, and they average smaller in size. In addition, species having narrow annual rings are desired by cross-arm purchasers. In this respect western larch has no equal among the softwood species. Neither can any other decay-resistant softwood so readily meet the limitation imposed on sapwood. A slope of 1 in 12, which is the cross grain allowed in the specification on which the bulk of cross arms are purchased, is readily met by Douglas fir, southern yellow pine, and western larch. Only in the limitations on checks will western larch find more difficulty in meeting cross-arm specifications than Douglas fir and southern yellow pine. Checks are about three times as prevalent in larch as in those species.

REFRIGERATORS

Western larch is used both in the small household refrigerators and in large ones of the type used in meat markets. In the household type the species is used principally for frames, bottoms, insulation, and backing. Its strength, nail and screw holding power, and high heartwood content are the properties valued for frames. No. 1 Common western larch dimension is commonly used for this purpose. The brownish color and narrow uniform ring growth are largely responsible for the use of western larch for refrigerator backing and bottoms. Ceiling or dressed and matched western larch of the C and Better or D grade is used for these items. No. 3 Common 1 inch thick by 8 or 10 inches wide is sometimes resawed and used for refrigerator insulation. As a thermal insulator, western larch has a higher heat conductivity than the lighter-weight woods, but the tightness and small size of knots and small amount of decay in the low grades of the species are advantages.

Western larch finish and ceiling are used principally for exterior trim in refrigerators for grocery stores and meat markets. It is used as an alternative for more expensive hardwoods as a front trim in the moderate-priced boxes. In more expensive boxes western larch ceiling is used for sides. In both the expensive and moderate-priced boxes the dark color of heartwood, combined with the " wire-grain " figure of edge-grained stock, is largely responsible for the use of the species for this purpose. The brown color of heartwood blends well with other trim, especially southern yellow pine. The dark color of western larch does not show dirt and hand marks on the sides of refrigerators so readily as would lighter-colored woods, and the hardness of the wood resists denting and marring. Western larch is only occasionally used for interior lining, since for this purpose the preference is for lighter colored and softer woods.

AUTOMOBILE BODIES

The use of softwoods in automobile bodies is increasing. In some of the smaller and lighter cars about 60 per cent of the wood used is softwood. In the heavier and larger cars softwoods are limited to those parts the property requirements of which are not exacting.

Southern yellow pine and Douglas fir are the principal softwoods used in automobile bodies. In the larger and heavier cars both species are used for floor boards, running boards, seat risers and frames, fillets, braces, and cleats. They carry no steel and are not subjected to heavy impact loads. Western larch lumber will serve as well as the species now used in such parts, but it is not so readily available. In some of the smaller cars, softwoods, particularly laminated Douglas fir (coast type), are used in more important structural parts, such as main sills, cross sills, and top or roof rails. Here nail-holding power, bending strength, and toughness are desired. Western larch has the same bending strength and toughness as Douglas fir (coast type) (figs. 11 and 14) and has a higher nail-holding power. In general, the properties of western larch indicate that it can be used for parts similar to those for which Douglas fir is successfully used. A comparison of the properties of western larch with those of red gum, a species widely used in the small type of cars, also

indicates the possibility of using western larch in automobile parts. Western larch has a higher nail-holding power and is stiffer and higher in compressive strength than red gum, but it is lower in bending strength and shock resistance and is not so uniform in texture.

The ease with which western larch can be glued is another property desired in a number of automobile-body parts. Sills are made of glued laminations, joints are glued, and other parts are built up. It is easy to glue western larch so as to obtain joints stronger than the wood.

Some of the growth characteristics of western larch are also favorable to its use in automobile bodies. The high heartwood content reduces trouble from decay, and the narrow uniform annual rings make for ease of working.

The use of western larch in automobile bodies is confined largely to running boards and floor boards. For running boards D Select 1 inch thick by 4 inches wide, dressed and matched boards are used. Floor boards are generally square-edged No. 1 and No. 2 Common.

The principal obstacle to the more extensive use of the species for automobile body parts is the comparatively small cut and stand. The stand of western larch, however, is sufficient to meet heavier demands than are now made on it and is larger than that of many of the hardwoods now used. Manufacturers of western larch must be prepared to meet a large demand over long periods of time if any appreciable amount of western larch is to be marketed for automobile parts.

BLEACHER AND STADIUM SEATS

Large quantities of lumber are used for seats and footboards in stadium and bleachers, but very little western larch has been used for this purpose. Douglas fir (coast type), southern cypress, redwood, southern yellow pine, and eastern spruce are the principal woods used.

There are two main types of stands: The stadium which has fixed seats on concrete, steel, or wood, and the bleacher, or temporary stand, which can be knocked down and moved from place to place. Stadium seats are usually exposed to weather the year round; temporary seats are usually exposed for only short periods or are used under cover. Bleacher seats are made largely of 1-inch stock, 6 to 12 inches wide; stadium seats are slats 1½ or 2 inches thick and from 2 to 4 inches wide, or single planks 8 to 12 inches wide.

The two types of stands have a number of requirements in common. Both require strength in bending to carry live loads; hardness to resist denting, scuffing, and marring; and holding power for screws in order that the seat may not break loose. Twisting is objectionable because it causes slats to pull loose from fastenings, and also makes the seat uncomfortable for the occupant. Cupping is objectionable because cupped seats hold water after rain. Exudation of pitch or coloring matter is especially objectionable because they injure clothing, and loose or raised grain is objectionable because of danger from splinters.

The two types differ, however, in some of their requirements. Decay resistance and painting characteristics are more important in exposed permanent seats than in temporary, knock-down seats.

Strength in bending, stiffness, and toughness, on the the other hand, are more important in bleacher seats than in stadium seats because failure of seats or footboards in bleacher seats often has more serious results for the occupants. In addition, the bleacher seats are subjected to hard usage in knocking down and erection when they are moved from place to place.

The properties and characteristics of western larch adapt it to both types of seats. It has about the same bending and compressive strength, toughness, decay resistance, and painting characteristics as Douglas fir (coast type), which is the wood most commonly used for such seats. Douglas fir is stiffer and has a higher splitting resistance, but western larch is harder and has a higher nail-holding power. In addition, western larch is less resinous and less subject to pitch defects and will therefore give less trouble from resin exudation. Both species stay in place well and normally will give little trouble from warping or cupping.

The hardness, strength, nail-holding power, and decay resistance of western larch are the properties that commend the wood most strongly for bleacher seats. Western larch also has few pitch defects, and when common grades are used, the small, tight character of the knots is an advantage over the common grades of other softwood species. Western larch will require more painting maintenance than the other woods commonly used for seats, except Douglas fir and southern pine, which are very similar to larch in paint-holding qualities. Western larch is more subject to checking than any of the commonly used woods and must be kept well painted if checking is to be prevented. The coating of end surfaces is also advisable.

The general conclusion drawn from the properties is that western larch is an excellent wood for stadium and bleacher seats and stands. Service records to confirm this conclusion are lacking. Such records would be of value in opening this market to western larch, for actual performance in service is necessary as the final proof of the adaptability of a wood for any purpose.

The value of western larch for bleacher and stadium seats can be materially increased by the application of a few well-known principles. Edge-grained material will give more satisfactory service because it holds paint better, presents a more uniform wearing surface, shrinks and swells less, checks less, and is less subject to loose and raised grain than flat-grained stock, but it costs more. In permanent seats exposed to weather, all-heartwood stock should be specified or pieces containing sapwood should be culled because the sapwood of all species rots quickly. Checking at bolt holes near the end of the seat can be reduced by coating the end surfaces as soon after cutting as possible. Hardened gloss oil is an excellent coating for this purpose.[25] and will prevent most of the end checking, which is particularly objectionable at bolt fastenings. The heart side of flat-grained boards, that is, the side farthest from the bark, should be placed down. This arrangement will reduce trouble from splinters resulting from raised or loose grain. Most of the foregoing principles can be profitably applied to all of the woods now used, but are especially applicable to western larch.

[25] A formula for the preparation of hardened gloss oil can be obtained from the Forest Products Laboratory, Madison, Wis.

SHIPPING CONTAINERS

Western larch is used for all types of shipping containers. No. 1 and No. 2 Dimension are the grades commonly used for heavy and export crating. Wooden boxes are made from all of the common grades. Frames for veneer boxes are commonly made from 1 by 4 inch pieces of No. 3 Common ripped into three equal parts. One by four-inch square-edged boards of D Select grade are used for tight cooperage. The D Select grade, as well as No. 1 and No. 2 Common grades, is used in slack cooperage.

The properties of western larch adapt the wood better to crating, especially heavy and export crating, than to boxes. Crating for heavy and valuable merchandise requires a wood with high strength and nail-holding power. In these properties western larch ranks with the best of the softwoods. (Fig. 19.) The weight and dark color of western larch, while objectionable in boxes, are not objectionable in crating for heavy valuable commodities or in crating for shipment by water. The weight of the wood is given little consideration in crating valuable commodities, for the failure of only an occasional crate will usually more than offset the saving in transportation costs that could be made by using a lighter and weaker wood. Cost of transportation by water-borne shipments is based on volume; hence the weight of the container is not an important item. Color and appearance are less important in crates than in boxes because commodities are sold more often in or from boxes than in crates.

Boxes made of western larch are heavy, strong, and dark-colored. The average weight of the canned-food boxes of western larch used in tests (*8*) at the Forest Products Laboratory was 9.44 pounds. The same type of box of aspen averaged about two-thirds and of western yellow pine about three-fourths of the weight of western larch boxes. In resistance to rough handling the western larch boxes were between those of western yellow pine and aspen, which were higher, and those of western hemlock, which were lower. All of these woods are used extensively for boxes and are recognized by the box trade as excellent woods for that purpose. The western larch boxes had a relatively small percentage of failures from cross breaks, the outstanding cause of failure being splitting in sides, tops, and bottoms. This type of failure indicated that the efficiency of the western larch boxes could be improved by using thinner lumber and more and smaller nails than were used with softer and lighter woods. It is, however, hardly possible that western larch boxes could be made the equal on a weight basis of boxes of western yellow pine or aspen. The dark color of western larch boxes is shown in Figure 32 which also shows the size and type of box used in the tests.

Western larch is not primarily a box wood. The percentage of the cut of the species used for boxes will probably never be so high as that of the lighter weight, lighter colored, softer, and weaker woods.

Tight cooperage must be slow to absorb liquids and not easily penetrated by them. It must be easily bent to shape and must stay in place well. Western larch meets these requirements about like Douglas fir (coast type), which is used largely for tight cooperage. Western larch shrinks more than the Douglas fir (coast type) and is not so stiff. On the other hand, it is harder and less resinous. A high percentage of western larch has narrow rings of uniform

width; consequently a high percentage of the material from the tree is adapted to the manufacturing of tight cooperage. Western larch tight cooperage is used principally for pickle barrels.

The common as well as the select grades of western larch are used for slack cooperage. The small, tight knots of western larch are therefore an advantage over the same grades of stocks of other softwood species. On the other hand, the dark color of the wood is a disadvantage in tubs, pails, and buckets.

POLES

Western larch has been used locally in small quantities for poles. Poles in the past have been chosen principally for a combination of light weight, narrow sap ring, and high decay resistance. Western red cedar is one of the principal sources of poles of this type. Western larch poles are decay resistant, have a narrow sap ring, but

FIGURE 32.—Western larch style 5 standard canned-food boxes used in the tests at the Forest Products Laboratory. Western larch made a strong, heavy, dark-colored box

are comparatively heavy. They are, however, strong. Heavy, strong, decay-resistant woods are rapidly entering the pole market. Such poles are usually treated with a preservative, either because they have a wide sapwood ring or because they are less decay resistant than species previously used. Southern yellow pine is the principal source of these heavy, strong poles although some Douglas fir is also used. Western larch can furnish heavy, strong, moderately decay-resistant poles. The availability of light, more decay resistant woods, such as western red cedar, or strong, more easily treated woods, such as lodgepole pine, in the "Inland Empire" has prevented and will probably continue to prevent the marketing of much western larch for poles.

PILING

Western larch makes an excellent pile because of its strength and moderate decay resistance. The wood has the strength necessary to withstand driving, and has the hardness to resist mashing under the driving hammer. The heartwood is moderately decay resistant and

the sapwood band narrow; consequently it can be used untreated. Under conditions favorable to decay western larch piling should be treated with a preservative if long life is desired. Western larch, along with Douglas fir and southern pine, is classed among the softwood species best adapted to use as piling.

PULPWOOD AND PAPER

Western larch is not especially well adapted to use in the manufacture of pulp or paper. Although it can be pulped by the sulphite, sulphate, soda, and ground-wood processes (*31*), it is not so suitable for the production of pulp by any of these processes as are the spruces, true firs, or hemlocks. It is heavier than any of these woods, which fact tends to increase the yield per cord. Its fiber length, 2.6 millimeters, is the same as that of white spruce. Its hardness, dark color, and resin content, however, are not favorable to its use as a pulpwood.

Western larch is best adapted to pulping by the sulphate process. By this process the wood is readily pulped, yielding 1,290 pounds of pulp per 100 cubic feet of solid wood. The pulp is of good quality and strong. It is suitable for use unbleached in the manufacture of fiber boards and of good quality kraft wrapping paper.

Western larch is also adapted to pulping by the soda process. The yields obtained with this process, however, are lower than those obtained with sulphate processes, and the pulp is not quite so high in quality. There will therefore probably be little or no use of soda process with western larch.

Western larch is not well adapted to pulping by the sulphite process. It reduces unevenly and with difficulty. The unbleached pulp has poor strength and color. It is difficult to bleach, requiring 15 to 25 per cent of bleach. The yield is about 1,200 pounds of pulp per cord (100 cubic feet of solid wood). Western larch pulp produced by the sulphite process may be used for low-grade wrapping paper and boards.

Mechanical pulp is produced with difficulty from western larch. The hardness of the wood results in high power consumption. About two and one-half times as much power is required as is required for white spruce. The pulp is rather coarse, decidedly brown in color, and of fair strength. It is unsatisfactory for use as newsprint because of its dark color. It can be used as a filling material for boards or for any purpose where a medium quality of ground wood is desired and brown color is not objectionable.

The probability of using any large portion of the stand of western larch for the manufacture of pulp and paper is not great. Sulphate is the only pulping process which produces a satisfactory quality and yield of pulp from western larch. The amount of raw material suitable for use with this process is larger than for any other. It includes large amounts of woods and mill waste of better pulping species which are available in the "Inland Empire" and along the Pacific coast. It is reasonable to expect that the paper and pulp industry will utilize these species before attempting to use western larch. In addition, pulp mills along the Pacific coast will have an advantage over any mill established in the western larch region due to the lower cost of transportation by water.

APPENDIX

The names of lumber adopted as official by the Forest Service are not always identical with the names adopted by the trade as American lumber standards. Where the names are not identical some confusion may result. Table 18 has therefore been prepared to show the American lumber standards name (*28*) corresponding to the Forest Service name used in this bulletin. The common and botanical names of the trees from which the lumber is cut are also shown. Other trade names for lumber from the various species can be found in the Forest Service check list of the forest trees of the United States (*24*).

TABLE 19.—*Lumber names used by the Forest Service in this bulletin and corresponding American lumber standards names*

Name used in bulletin	American lumber standards name	Common name of tree	Botanical name of tree
Western red cedar	Western red cedar	Western red cedar	Thuja plicata.
Southern cypress	Red cypress (coast type)	Southern cypress	Taxodium distichum.
	Yellow cypress (inland type)	do	Do.
	White cypress (inland type)	do	Do.
Douglas fir (coast type)	Douglas fir (coast type)	Douglas fir	Pseudotsuga taxifolia.
Douglas fir ("Inland Empire" type).	Red fir (intermountain type)	do	Do.
Douglas fir (Rocky Mountain type).	Red fir (Rocky Mountain type).	do	Do.
Eastern hemlock	Eastern hemlock	Eastern hemlock	Tsuga canadensis.
Western hemlock	West coast hemlock	Western hemlock	Tsuga heterophylla.
Western larch	Western larch	Western larch	Larix occidentalis.
Southern yellow pine [1]	Southern pine [1]		Pinus.
Loblolly pine	Loblolly pine	Loblolly pine	Pinus taeda.
Shortleaf pine	Shortleaf pine	Shortleaf pine	Pinus echinata.
Longleaf pine	Longleaf pine	Longleaf pine	Pinus palustris.
Northern white pine	Northern white pine	Northern white pine	Pinus strobus.
Western white pine [4]	Idaho white pine	Western white pine	Pinus monticola.
Western yellow pine	California white pine	Western yellow pine [2]	Pinus ponderosa.[2]
	Pondosa pine	do	Do.
Redwood	Redwood	Redwood	Sequoia sempervirens.
Eastern spruce [3]	Eastern spruce [3]	Red spruce	Picea rubra.
		White spruce	Picea glauca.
		Black spruce [3]	Picea mariana.
Tamarack	Tamarack	Tamarack	Larix laricina.

[1] Forest Service includes five and American lumber standards four other species under the name southern yellow pine, but no data on these species are shown in this bulletin.
[2] Jeffrey pine (*Pinus Jeffreyi*) is marketed along with western yellow pine which it closely resembles
[3] Black spruce is not included in the averages shown in this bulletin.
[4] Changed to ponderosa pine after this bulletin went to press.

LITERATURE CITED

(1) ALLEN, T. E.
1923. FOREST FIGURES FOR PACIFIC COAST STATES. U. S. Senate Select Committee on Reforestation. [18] p.

(2) AMERICAN RAILWAY ENGINEERING ASSOCIATION.
1926. REPORT OF COMMITTEE VII—WOODEN BRIDGES AND TRESTLES. Bul. Amer. Ry. Engin. Assoc. 27 (284) : 829–912.

(3) AUSTIN, L. W., and EASTMAN, C. W.
1902. ON THE RELATION BETWEEN HEAT CONDUCTIVITY AND DENSITY IN SOME OF THE COMMON WOODS. Wis. Acad. Sci., Arts and Letters, Trans. 13: [539]–542, illus.

(4) BOWE, E. E.
1929. LUMBER IN CAR CONSTRUCTION. South. Lumberman 135 (1757) : 76.

(5) BRADNER, M., and FULLAWAY, S. V., JR.
1927–28. SIZE OF TIMBER, AMOUNT OF DEFECT, IMPORTANT FACTORS IN LUMBERING. AN ANALYSIS OF THEIR EFFECT UPON PRODUCTION COSTS AND VALUES AND THEIR CONSEQUENT INFLUENCE ON PROFITABLE TREE AND LOG UTILIZATION IN THE "INLAND EMPIRE." Timberman 29 (2) : 38–40, 44, 46, 48; (3) : 40–42, 44, 46; (4) 62–63; (6) : 162–164, 166, 174.

(6) BROWNE, F. L.
1930. PROPERTIES OF WOOD THAT DETERMINE THE SERVICE GIVEN BY EXTERIOR PAINT COATINGS. Amer. Paint Jour. 14: 22–78, illus.

(7) ———
1930. EFFECT OF PRIMING COAT REDUCTION AND SPECIAL PRIMERS ON THE SERVICE GIVEN BY PAINT COATINGS ON DIFFERENT WOODS. Indus. and Engin. Chem. 22: 847–854, illus.

(8) CARLSON, T. A.
1929. SUITABILITY OF LITTLE-USED SPECIES OF WOOD FOR SHIPPING CONTAINERS. Barrel and Box 34 (1) : [15]–19, illus.

(9) CLINE, M., and HEIM, A. L.
1912. TESTS OF STRUCTURAL TIMBERS. U. S. Dept. Agr., Forest Serv. Bul. 108, 123 p., illus.

(10) CUNNINGHAM, R. N., FULLAWAY, S. V., JR., and WHITNEY, C. N.
1926. MONTANA FOREST AND TIMBER HANDBOOK. Mont. State Univ. Studies no. 1, 162 p., illus.

(11) GOSS, O. P. M.
1913. MECHANICAL PROPERTIES OF WESTERN LARCH. U. S. Dept. Agr., Forest Serv. Bul. 122, 45 p., illus.

(12) KOEHLER, A.
1917. GUIDEBOOK FOR THE IDENTIFICATION OF WOODS USED FOR TIES AND TIMBERS. U. S. Dept. Agr., Forest Serv. Misc. Pub. RL–1, 79 p., illus.

(13) MCELHANNEY, T. A., and PERRY, R. S.
1927. SOME COMMERCIAL SOFTWOODS OF BRITISH COLUMBIA; THEIR MECHANICAL AND PHYSICAL PROPERTIES. Canada Dept. Int., Forest Serv. Bul. 78, 44 p., illus.

(14) MARKWARDT, L. J.
1930. COMPARATIVE STRENGTH PROPERTIES OF 164 WOODS FOR CROSSTIES. Crosstie Bul. 11(9) : 6–14.

(15) ———
1930. COMPARATIVE STRENGTH PROPERTIES OF WOODS GROWN IN THE UNITED STATES. U. S. Dept. Agr. Tech. Bul. 158, 39 p., illus.

(16) ———
1931. THE DISTRIBUTION AND THE MECHANICAL PROPERTIES OF ALASKA WOODS. U. S. Dept. Agr. Tech. Bul. 226, 80 p., illus.

(17) ——— and GAHAGAN, J. M.
1929. NAIL HOLDING TESTS MADE. EXHAUSTIVE EXPERIMENTS COVERING WIDE VARIETY OF WOODS COMPLETED BY ENGINEERS OF FOREST PRODUCTS LABORATORY, MADISON, WISCONSIN. Timberman 30(10) : 142–143, illus.

(18) NEWLIN, J. A.
1927. UNIT STRESSES IN TIMBER. Amer. Soc. Civ. Engin. Trans. 91: 400–407, illus.
(19) PECK, E. C.
1928. SHRINKAGE OF BOARDS OF DOUGLAS FIR, WESTERN YELLOW AND THE SOUTHERN PINES. Amer. Lumberman no. 2774: 52–54, illus.
(20) ROWLEY, F. B.
1923. TRANSMISSION OF HEAT THROUGH BUILDING MATERIALS. Minn. Univ. Engin. Expt. Sta. Bul. 3, 74 p., illus.
(21) ———
1929. RESULTS OF THERMAL CONDUCTIVITY TESTS ON LUMBER. Minn. Univ. Rpt. 8 p.
(22) SNYDER, T. E.
1930. PREVENTING DAMAGE BY TERMITES OR WHITE ANTS. U. S. Dept. Agr. Farmers' Bul. 1472, 22 p., illus. (Revised ed.)
(23) STOKES, W. B.
1925. CANADIAN SOFTWOODS. Canada Dept. Int., Forestry Branch Circ. 19, 13 p., illus.
(24) SUDWORTH, G. B.
1927. CHECK LIST OF THE FOREST TREES OF THE UNITED STATES. THEIR NAMES AND RANGES. U. S. Dept. Agr. Misc. Circ. 92, 295 p.
(25) THELEN, R.
1929. KILN DRYING HANDBOOK. U. S. Dept. Agr. Bul. 1136, 96 p., illus. (Revised.)
(26) TRUAX, T. R.
1929. THE GLUING OF WOOD. U. S. Dept. Agr. Bul. 1500, 78 p., illus.
(27) UNITED STATES DEPARTMENT OF AGRICULTURE.
[n. d.] SIGNIFICANCE OF THE "FACTOR OF SAFETY" IN WORKING STRESSES FOR STRUCTURAL TIMBERS. U. S. Dept. Agr., Forest Prod. Lab. Tech. Note 222, 3 p.
(28) UNITED STATES DEPARTMENT OF COMMERCE, BUREAU OF STANDARDS.
1929. LUMBER. U. S. Dept. Com., Bur. Standards Rev. Simplified Pract. Recommendation R 16–29, 94 p., illus.
(29) ———
1926. RECOMMENDED BUILDING CODE REQUIREMENTS FOR WORKING STRESSES IN BUILDING MATERIAL. REPORT OF BUILDING CODE COMMITTEE, JUNE 1, 1926. U. S. Dept. Com., Bur. Standards Elimination of Waste Ser. BH9, 53 p., illus.
(30) VAN DUSEN, M. S.
1920. THE THERMAL CONDUCTIVITY OF HEAT INSULATORS. Refrig. Engin. 7: 202–231, illus. [Also published in Jour. Amer. Soc. Heating and Ventilating Engin. 26: 625–656, illus.]
(31) WELLS, S. D., and RUE, J. D.
1927. THE SUITABILITY OF AMERICAN WOODS FOR PAPER PULP. U. S. Dept. Agr. Bul. 1485, 102 p., illus.
(32) WESTERN PINE MANUFACTURERS' ASSOCIATION.
1929. STANDARD GRADING RULES FOR PONDOSA PINE, CALIFORNIA WHITE PINE, SUGAR PINE, IDAHO WHITE PINE, LARCH, DOUGLAS FIR, WHITE FIR, SPRUCE, AND CEDAR LUMBER. 69 p., illus. Portland, Oreg.
(33) WILSON, T. R. C.
1921. THE EFFECT OF SPIRAL GRAIN ON THE STRENGTH OF WOOD. Jour. Forestry 19: 740–747, illus.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

SOME PHYSICAL PROPERTIES OF STARCH PASTES WHICH AFFECT THEIR STIFFENING POWER ON FABRICS [1]

By MARGARET S. FURRY, *Assistant Textile Chemist, Textiles and Clothing Division, Bureau of Home Economics*

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INTRODUCTION

As part of a series of studies on home laundering, an attempt has been made to evaluate the materials and methods that may be employed in sizing fabrics. In connection with the work on stiffness (*17*) [2] attention was directed to those physical properties of starch pastes that seem to influence the stiffness of fabrics sized with the pastes.

Although several investigators (*5*, *7*, *9*, *14*, *15*, *24*) have studied the relationship between penetration of starch pastes into yarns and fabrics and the apparent viscosity or consistency of the pastes, there has been no correlation of these facts with any properties of sized fabrics. It is the purpose of this bulletin to point out the correlation of fabric stiffness produced by various starch pastes to the consistency of these pastes and to their penetrating and coating powers on the fabric. Size measurements were taken of both the raw and swollen starch granules, consistency determinations of the starch pastes were made at one concentration and temperature, and the penetrating and coating powers of the starches were determined by examining cross sections of the sized yarns and fabric. These investigations were carried out with potato, corn, wheat, rice, canna, and dasheen starches. Canna and dasheen starches have not heretofore been used in the sizing of textiles, but since the United States Department of Agriculture has been interested in cultivating the plants and in the possible extension of the use of their products, a study of the properties of these starches is being made.

[1] Acknowledgment is made to Ruth E. Elmquist, of the Textiles and Clothing Division, for cooperation in determining the rate of flow of starch pastes; to Virginia Hefty and Eleanor Bowen for general laboratory assistance; to W. H. Herschel and R. Bulkley, of the United States Bureau of Standards, for helpful suggestions on consistency measurements of the starch pastes: and to M. L. Fobert, of the section of illustrations, United States Department of Agriculture, for taking the photomicrographs used in this bulletin.

[2] Italic numbers in parentheses refer to Literature Cited, p. 16.

THE STARCHES

Photomicrographs of the starches studied are shown in Plate 1, A to G inclusive. The potato, canna, corn, wheat, and rice starches, according to descriptions given by Reichert (*18*) are true to type. These were prepared as described by Peterson and Dantzig (*17*) from Fortuna rice, Kharkof hard-winter wheat, Russet Rural potatoes, and Boone County White corn. The edible-canna starch, which was obtained from J. C. Ripperton of the Hawaii Agricultural Experiment Station, came from canna grown in the Waimea district of Hawaii. It had been extracted according to the method described by Ripperton and Goff (*20*). The dasheens (*Colocasia esculenta* (L.) Schott) (*23*) from which the dasheen starch was prepared are a species belonging to the Aroideae and are somewhat similar to the plant popularly known as elephant-ear. The tubers were grown in Florida and were provided through the courtesy of R. A. Young, Bureau of Plant Industry, United States Department of Agriculture.

In extracting the starch from dasheens the tubers were peeled and finely ground. The pulp was put in heavy muslin bags and worked by hand in tubs of distilled water which was changed frequently. The washing was continued until the final wash water remained almost clear. Then the wash waters were combined, and the starch was centrifuged out. After several washings in fresh distilled water and centrifuging, the starch was washed with alcohol, tested for protein with Millon's reagent, ether-washed until free from fat, air-dried at room temperature and put through a 70-mesh sieve. It was necessary to use the centrifuge each time the starch was washed because the dasheen-starch granules are extremely small, and a gummy substance present in the dasheen prevents rapid settling of the granules when suspended in water.

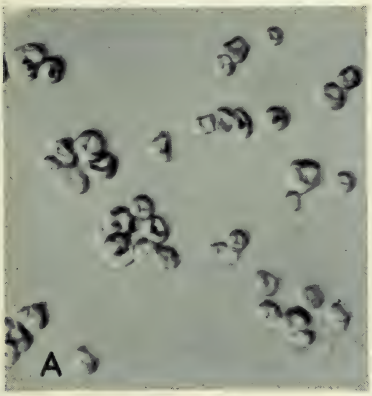
The dasheen-starch granules, which are the smallest starch granules known, occur sometimes in small aggregates but are mostly isolated. The most conspicuous forms appear to be irregular or rounded polygonal shapes. They have distinct, clear-cut, and somewhat concave facets. The hilum is small, fairly distinct, usually situated near the center, and often appears as a smooth hole. The striae are either invisible or indistinct.

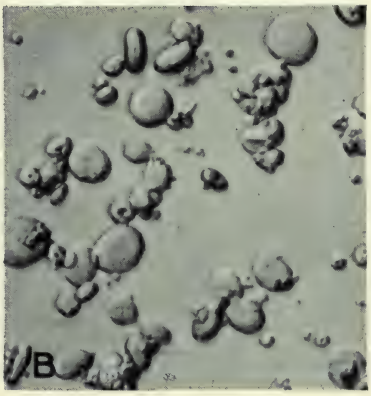
SIZE OF THE STARCH GRANULES

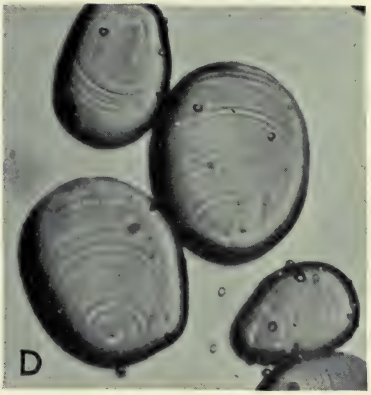
In order to describe more fully the starches used in this study, measurements were made of the size of both the raw and the swollen starch granules. The latter are of special interest because most investigators (*24*) now believe that as starch granules are heated in water to form a paste they swell but do not ordinarily disintegrate or become disrupted, and also because it is generally accepted (*1, 9, 21, 22*) that the number and size of swollen starch granules in a paste and the consistency of that starch paste are closely related.[3]

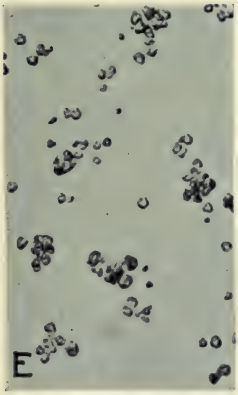
From various observations Alsberg (*1*) concludes that starch pastes, unless specially treated to disintegrate the particles, are not true colloidal solutions but are suspensions of swollen granules. He also believes that the viscosity of a paste depends in a large part upon the anatomical structure of the swollen granules. He attributes the swelling of the granules to three factors: Rigidity, inherent swelling

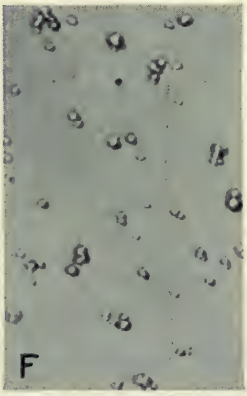
[3] CHAPMAN, O. W., PROPERTIES OF STARCH WITH RELATION TO TIME OF FORMATION OF STARCH GELS. 1927. [Unpublished thesis. Iowa State Col. Agr. Mechanic Arts, Ames.]

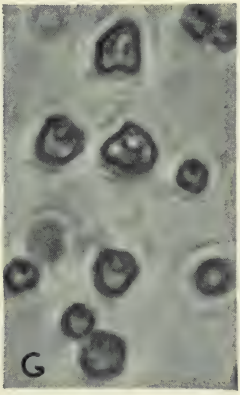












PHOTOMICROGRAPHS OF RAW STARCH GRANULES

A, Corn starch; B, wheat starch; C, potato starch; D, canna starch; E, rice starch; F, dasheen starch; G, dasheen starch. A–F × 250; G × 1,600.

power of the granule substance, and the relation of the mass of the swelling substance to the surface area of the granule. This third factor, which is the relation of increase of volume of spheres to the increase in surface area, indicates that large starch granules have greater mass of swelling substance exerting pressure on each unit of granular surface than smaller ones. Therefore, as Alsberg states, of two granules having the same rigidity but different diameters, the larger one will swell more readily and probably sooner, as the temperature is raised, than the smaller one. This is because the greater mass of the larger will exert pressure to distend its granule structure before the structure of the smaller one has been sufficiently softened to cause it to swell. It seems, therefore, from Alsberg's work, and Chapman [4] agrees in his work on starches, that larger granules begin swelling at a lower temperature than smaller ones and that the swelling of the smaller granules is a slower process.

Sprockhoff and Parlow (*21*) in an effort to find the comparative value of small and large potato-starch granules separated the small from the large and made viscosity measurements on the respective pastes. These authors report that small granules of potato starch, if care has been maintained in the manufacture, show even a higher viscosity than the large granules. It must be remembered, however, as Alsberg (*1*) and Harrison (*9*) have pointed out, that potato starch presents an exceptional behavior, in that the granules when heated in water not only swell but gradually fragmentize and disintegrate. There is, therefore, the possibility that the viscosity of the pastes used by Sprockhoff and Parlow was low because the large granules had become disrupted.

Ripperton (*19*), on studying the physicochemical properties of three samples of edible-canna and two samples of potato starches, measured the differences in the swelling power of the starch granule and the viscosity of their pastes at various concentrations. He concluded that the swelling power and viscosity of these starches are not directly proportional but that there is a direct relationship between the viscosity and the product of the concentration of the paste and the volume or "swell" of the swollen starch granules. He found that potato starch swells more and gives a higher viscosity than canna starch.

Chapman [4] noticed for rice, corn, wheat, and potato starch pastes of 3 per cent concentration that the temperature of maximum viscosity varied with the average diameter of the respective starch granules.

Taylor (*22*) on trying to rupture cornstarch granules by grinding the dry grains and shaking and grinding starch pastes, found that complete or partly complete rupturing of the granules is not easily accomplished. From microscopical examination, viscosity measurements, and determinations of the amount of the two constituents, α and β amylose, in the starch paste, he concluded that the number of swollen granules, high paste viscosity, and high α-amylose content of a starch paste are definitely interrelated.

Harrison (*9*) found in his viscosity measurements of wheat, corn, rice, and potato starch pastes that each showed a gradual increase in viscosity with time of heating up to a maximum point, after which there was a decrease. In the case of potato starch, there was a marked

[4] CHAPMAN, O. W. Op. cit. (See footnote 3.)

decrease in viscosity which he explains as being caused by the great variation in size of the granules and the breaking up of the swollen granules as they flow down the capillary tube. When starch pastes were heated to a temperature just above their swelling point, the paste cooled, and the swollen granules separated by centrifuging, he found that the volume of the swollen granules was directly proportional to the viscosity of the paste, regardless of what starch was used.

There are many other factors which also affect the consistency of pastes, but this brief review of the work of previous investigators shows that the number and size of the swollen starch granules in a paste greatly influence the viscosity of that paste.

In order to measure the granule size of the starch in this study, a filar micrometer attachment for the microscope, which had been calibrated by the United States Bureau of Standards, was used. The length and width of a large number of raw starch granules were measured at a magnification of 537.5. The micrometer held a 20-millimeter (×12.5) eyepiece, and a 4-millimeter (×43) objective of the microscope was used. The results of these measurements are given in Table 1. The standard deviation in this table is the square root of the sum of the squared deviations from the average divided by the number of granules measured. The coefficient of variation is the standard deviation expressed as percentage of the average. The swollen granules of rice, dasheen, and corn were also measured with the 4-millimeter objective, but for wheat, potato and canna it was necessary to use the 16-millimeter (×10) objective, making the magnification 125 diameters. Table 1 also gives the measurements for the swollen starch granules.

TABLE 1.—*Size of starch granules from various sources*

RAW STARCH GRANULES

Source of starch	Length				Width			
	Granules measured (N_1)	Average length (L_1)	Standard deviation (σ)	Coefficient of variation $\left(\frac{\sigma}{L_1}\right)$	Granules measured (N_1)	Average width (W_1)	Standard deviation (σ)	Coefficient of variation $\left(\frac{\sigma}{W_1}\right)$
	Number	*Microns*	*Microns*	*Per cent*	*Number*	*Microns*	*Microns*	*Per cent*
Potato	65	50.3	15.0	30.0	65	33.0	9.6	29.1
Canna	50	63.5	17.1	26.9	50	43.5	12.2	28.0
Corn	65	13.8	4.3	31.2	65	12.1	3.7	30.6
Wheat	50	13.5	7.5	55.6	50	11.2	6.3	56.3
Rice	50	5.7	0.89	15.6	50	4.8	0.81	16.9
Dasheen	50	4.1	1.0	24.4	50	3.3	0.93	28.2

SWOLLEN STARCH GRANULES

Source of starch	Length				Width			
	Granules measured (N_2)	Average length (L_2)	Standard deviation (σ)	Coefficient of variation $\left(\frac{\sigma}{L_2}\right)$	Granules measured (N_2)	Average width (W_2)	Standard deviation (σ)	Coefficient of variation $\left(\frac{\sigma}{W_2}\right)$
	Number	*Microns*	*Microns*	*Per cent*	*Number*	*Microns*	*Microns*	*Per cent*
Potato	75	324.8	113.3	34.9	75	200.3	73.8	36.8
Canna	75	279.9	69.5	24.8	75	221.5	50.7	22.9
Corn	75	59.8	13.6	22.7	75	49.7	11.9	23.9
Wheat	75	70.0	28.6	40.9	75	56.9	23.6	41.5
Rice	55	10.5	2.3	21.9	55	8.8	1.8	20.5
Dasheen	60	9.3	1.7	18.3	60	7.5	1.3	17.3

The size of the raw granules of potato, canna, corn, wheat, and rice agree very well with that reported by Reichert (*18*). Barrett (*2*) states [5] that the starch grains of taro varieties (including dasheen) range in size from 1 to 3 microns. Alsberg (*1*) in discussing the swelling of starch granules reports that potato swells about 40 times, canna 16.5 times, and wheat only 8 times its natural size. A comparison of the amount of swelling of the different starches used in this study was made by calculating the ratio of the swollen-granule size to the raw-granule size. These values for both the length and width of the granules are given in Table 2. From the results reported in Table 1 it is also evident that different starches swell to different degrees even though the size of their raw granules is somewhat the same. A study of the coefficient of variation in length and width of the swollen granules in Table 1 emphasizes the great variation in the size of starch granules in a given paste.

TABLE 2.—*Ratio of size of swollen starch granules to size of raw granules in starches from different sources*

Source of starch	$\frac{L_2}{L_1}$[1]	$\frac{W_2}{W_1}$[1]	Source of starch	$\frac{L_2}{L_1}$[1]	$\frac{W_2}{W_1}$[1]
Potato	6.46	6.07	Wheat	5.19	5.08
Canna	4.41	5.09	Rice	1.84	1.83
Corn	4.33	4.11	Dasheen	2.27	2.27

[1] Symbols refer to values in Table 1.

CONSISTENCY OF STARCH PASTES

Flow tests were made by Ruth E. Elmquist and the writer on the six starches—potato, canna, corn, wheat, rice, and dasheen—at one concentration (3.7 per cent). Pastes were made according to the method previously developed in connection with this study (*17*). In this procedure an accurately weighed sample of desiccated starch was mixed with a definite quantity of cold distilled water. This cold-water-starch suspension was poured slowly into a definite quantity of hot distilled water, kept in motion by a mechanical stirrer, and the paste was subsequently heated in a boiling-water bath for one-half hour. A buret consistometer similar to that of Herschel and Bulkley (*12*) was made by joining, with rubber tubing, a capillary tube to an ordinary 25-cubic centimeter buret. This was fitted into position in a long tube leading to the bottle which was to receive the starch paste coming through the consistometer. The entire apparatus was placed in a large glass-sided water jacket full of hot water kept in motion with a motor-driven mechanical stirrer. The temperature of the bath was maintained at 87° C., which was the temperature of sizing, and regulated to stay within ± 0.1° of 87°. In order to prevent flow of the paste in the consistometer while it was coming to temperature in the bath, for the 15 minutes allowed, rubber tubing with its free end held tight by a pinch clamp was pulled over the top of the buret. To make a run, this rubber tubing was cut quickly and the descent of the meniscus observed. The time for the flow of the paste was taken at every 5 cubic centimeters for 25 cubic centimeters. Flow tests for corn,

[5] This statement was based on original measurements made by B. J. Howard, Bureau of Chemistry and Soils, U. S. Department of Agriculture.

TABLE 3.—*Flow-test data of starch pastes (3.7 per cent starch)*

Starch	Density of starch pastes	Consistometer A					Consistometer B				
		Determinations averaged	Readings	Time of flow (t)	Average rate of flow (q)	Average pressure (P)	Determinations averaged	Readings	Time of flow (t)	Average rate of flow (q)	Average pressure (P)
	Gm. per c.c.	*Number*	*C.c.*	*Seconds*	*C.c. per sec.*	*Gm. per sq. cm.*	*Number*	*C.c.*	*Seconds*	*C.c. per sec.*	*Gm. per sq. cm.*
Potato[1]	0.9804	4	0	0							
					0.152	32.86					
			5	32.9							
					.118	27.64					
			10	75.3							
					.0810	22.41					
			15	137							
					.0472	17.17					
			20	243							
					.0242	11.91					
			25	450							
Canna[1]	.9810	4	0	0							
					.187	32.88					
			5	26.7							
					.141	27.65					
			10	62.2							
					.0984	22.42					
			15	113							
					.0568	17.18					
			20	201							
					.0287	11.92					
			25	375							
Corn	.9814	10	0	0				0	0		
					1.02	32.90				0.239	30.16
			5	4.9				5	20.9		
					.781	27.67				.174	25.04
			10	11.3				10	49.6		
					.538	22.44	3			.116	19.75
			15	20.6				15	92.6		
					.327	17.18				.0638	14.56
			20	35.9				20	171		
					.156	11.92				.0262	9.26
			25	67.9				25	362		
Wheat	.9807	5	0	0				0	0		
					1.52	32.87				.368	30.13
			5	3.3				5	13.6		
					1.28	27.64				.289	25.02
			10	7.2				10	30.9		
					.980	22.42	7			.209	19.73
			15	12.3				15	54.8		
					.641	17.17				.130	14.55
			20	20.1				20	93.3		
					.379	11.91				.0644	9.26
			25	33.3				25	171		
Rice	.9812	4	0	0				0	0		
					.746	32.89				.172	30.15
			5	6.7				5	29.0		
					.617	27.66				.129	25.03
			10	14.8				10	67.9		
					.455	22.43	4			.0924	19.74
			15	25.8				15	122		
					.299	17.18				.0568	14.56
			20	42.5				20	210		
					.166	11.92				.0262	9.26
			25	72.7				25	401		
Dasheen	.9813	7	0	0				0	0		
					1.06	32.89				.181	30.15
			5	4.7				5	27.7		
					.834	27.66				.139	25.03
			10	10.7				10	63.8		
					.649	22.43	4			.0996	19.74
			15	18.4				15	114		
					.424	17.18				.0625	14.56
			20	30.2				20	194		
					.250	11.92				.0314	9.26
			25	50.2				25	353		

[1] Flow tests for these starches were not made with Consistometer B.

wheat, rice, and dasheen pastes were made with two different capillaries because the pastes varied considerably in consistency. For potato and canna pastes only the larger capillary was used. Each determination was from a freshly prepared sample, and the results given in Table 3 are averages of from 3 to 10 determinations.

The consistometers were calibrated by flow tests with standard samples of oils supplied by the United States Bureau of Standards. Data on the calibrating liquids are contained in Table 4.

TABLE 4.—*Calibrating liquids*

Liquid	Temperature	Density (ρ)	Viscosity (η)	Flow time of 25 c. c. (t)	
				Consistometer A	Consistometer B
	° C.	Gm. per c. c.	Poises	Seconds	Seconds
Water	25	0.997	0.00894	6.1	25.7
Oil No. 1	25	.865	.560	119	769
Oil No. 2	25	.841	.187	41.5	266

The length of each capillary was measured with a millimeter rule. From the data obtained in the flow tests of the oils the diameters of the capillaries were calculated according to the method described by Herschel and Bulkley (*12*). The results are given in Table 5.

TABLE 5.—*Dimensions of the capillaries used*

Capillary for consistometer	A	B
Length in centimeters (l)	5.92	3.27
Inside diameter in centimeters (d)	.2020	.1138
Ratio $\frac{d}{l}$	.0341	.0348

The average head, h, for the two consistometers was also calculated by the equation of Herschel and Bulkley (*12*). The instrumental constant C and the kinetic energy constant K, the values for which are found in Table 6, were obtained from the data of the flow tests of oils given in Table 4 and from the equation $\frac{\rho}{\eta}=\frac{C}{t-\frac{K}{t}}$, given by Clibbens and Geake (*4*). In this equation, ρ represents the density, η the viscosity, and t the time of flow of the viscous material. The values of the constants C and K may be substituted in this equation in order to calculate the apparent viscosity of the starch pastes.

TABLE 6.—*Constants for consistometers*

Constants for consistometer	A	B
C (instrumental constant)	183.6	1,188.0
K (kinetic energy constant)	27.17	386.6

Since the viscosity of a plastic material is a variable depending on the relation between pressure and rate of flow, it was thought best to describe the consistency of each starch paste by its yield shear value, f, and its mobility μ. Herschel and Bulkley (*11*) working with rubber-benzene solutions and Bingham (*3*) with paints have shown that for some plastic materials these two terms are nearly constant in value and do not depend on the rate of flow or on the dimensions of the capillary used. It was hoped that this would also be true of starch pastes. The yield shear value and mobility for each starch paste was therefore calculated according to the following equations:

$$f=\frac{pdg}{4l} \quad \text{and} \quad \mu=\frac{128ql}{\pi gd^4(P-p)}$$

where f = yield shear value (dynes per square centimeter)
p = yield value (gram per square centimeter)
g = acceleration of gravity = 981 centimeter per second per second
d = diameter of capillary in centimeters
l = length of capillary in centimeters
q = rate of flow of paste (cubic centimeters per second)
μ = mobility (square centimeters per dyne-second)
P = average pressure of flow (grams per square centimeter)
$P=\rho\times h$

When the rate of flow of the starch paste, q, was plotted against the average pressure, P, to obtain the flow-pressure diagram, the yield value, p, was obtained as the intercept of the upper straight portion of the graph, prolonged on the abscissa axis. Since the kinetic energy pressure correction for capillary A was only slightly greater than 1 per cent in the extreme case of wheat starch and for capillary B was considerably less, it has been ignored in these calculations. Figures 1 and 2 are flow-pressure diagrams for the starch pastes. Table 7 gives the calculated results of the consistency of the starch pastes. The values of the rate of flow, q, used in calculating the mobility, μ, in this table are taken from the flow-pressure diagrams rather than from the actual experimental values.

TABLE 7.—*Consistency of starch pastes (3.7 per cent starch)*

Starch	Consistometer A			Consistometer B		
	Yield value (p)	Yield shear value (f)	Mobility (μ)	Yield value (p)	Yield shear value (f)	Mobility (μ)
	Gm. per sq. cm.	*Dynes per sq. cm.*	*Sq. cm. per dyne-sec.*	*Gm. per sq. cm.*	*Dynes per sq. cm.*	*Sq. cm. per dyne-sec.*
Potato	10.40	87.03	1.01			
Canna	10.60	88.70	1.25			
Corn	9.60	80.34	6.42	9.60	81.94	9.28
Wheat	6.05	50.63	8.61	6.05	51.64	12.37
Rice	6.80	56.90	4.25	6.80	58.04	5.86
Dasheen	6.15	51.47	5.82	6.15	52.49	5.97

Table 7 shows some differences in mobility and in yield shear value with the two capillaries (consistometers A and B). In mobility values alone, however, there was fairly close agreement with both capillaries for the rice and for the dasheen pastes. This may be accounted for in some measure by the fact that, as is shown in Table 1, these starch pastes are composed of smaller and more uniformly sized swollen granules than corn and wheat. The work of Herschel and Bergquist (*10*) agrees with the present study in so far as these authors also obtained varying results for rigidity and yield shear values on starch pastes when different capillaries were used. On the

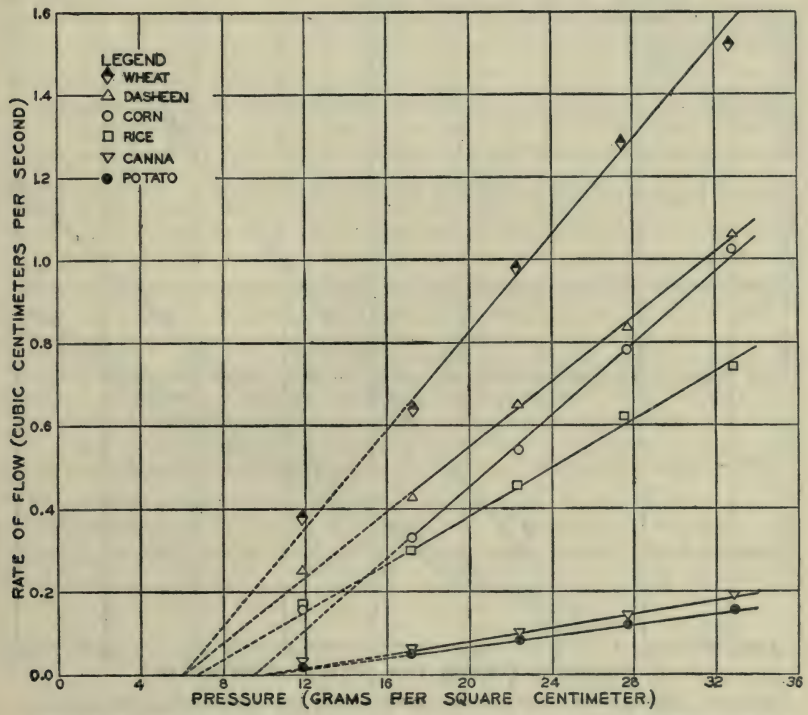


FIGURE 1.—Flow-pressure diagram of starch pastes (3.7 per cent starch), using consistometer A

other hand Farrow, Lowe, and Neale (*6*), under the special conditions of their experiment on flow tests of formaldehyde-treated starch pastes of various concentrations, obtained constant values with different capillaries. Their conditions such as kind of starch, concentration of paste, etc., are, however, quite different from those in the present study.

PENETRATING AND COATING POWERS OF STARCH PASTES

The comparative penetrating and comparative coating powers of the different starch pastes on fabric and on yarns raveled from the fabric were determined qualitatively by microscopic examination of cross sections of the starched yarns and fabric. Other investigators (*5, 8, 14, 24*) have studied the penetrating and coating powers of

starch mixtures by this method, and some have determined the amount of penetration by quantitative methods.

Krais and Gensel (*14*) studied the sizing of cotton yarn using different starches and sizing mixtures. They reported that penetration of the size into the yarn is greater the higher the degree of dispersion of the starch in the size and the lower the viscosity of the sizing materials. Greater penetration was also observed with hydrolyzed

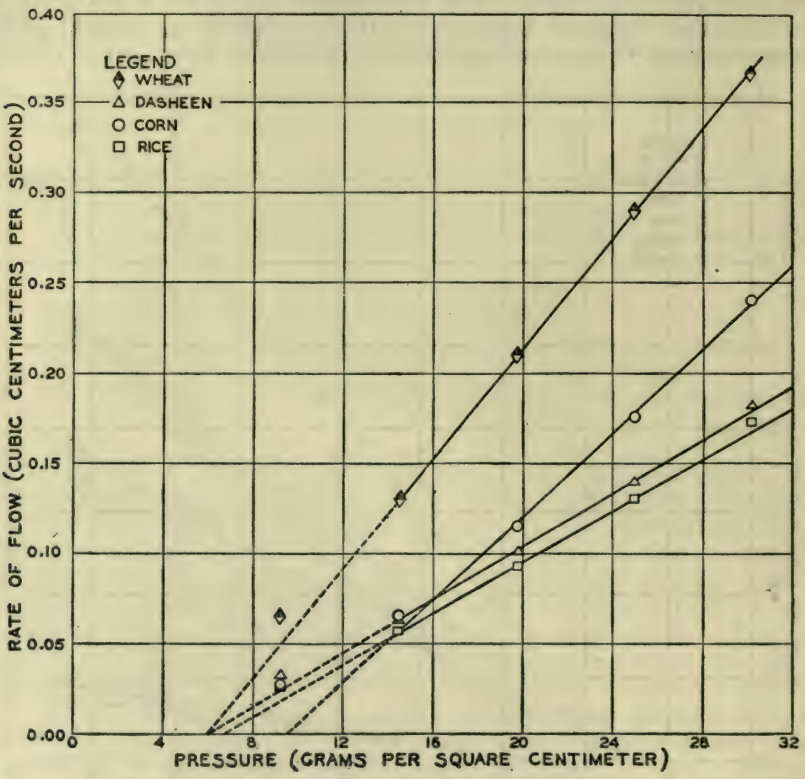


FIGURE 2.—Flow-pressure diagram of starch pastes (3.7 per cent starch), using consistometer B

than with unhydrolized starches and with a size containing wheat starch than with one containing potato starch.

Grimshaw (*8*) on sizing cotton yarns with various sizing mixtures found that yarns sized with corn starch were more deeply penetrated than most of those treated with potato starch.

Farrow and Jones (*5*) in an examination of the process of sizing cotton yarns on an experimental tape frame reported that the amount of sizing picked up by yarns depends on the construction of the yarn and on the viscosity of the size. They also stated that the penetration of the size into the yarns is determined by physical conditions which control flow, and is increased by pressure, by repetition of squeezing, or by prolonged pressure.

It is therefore generally understood that penetration of sizes into yarns and fabrics is influenced by the viscosity of the starch paste

and by such other factors as twist and construction of yarns, temperature of sizing, and concentration of the paste.

Parker (*15*) believes that penetration depends also on the size of the starch granule. He found that of raw-starch granules, rice starch penetrates cotton fabric most freely, and that the degree of penetration for wheat, maize, and potato starches decreases in the order given. Both the rice starch and the small granules of wheat starch penetrate the yarns of the fabric to a marked extent.

In this study the penetrating power of a starch is considered as the extent to which the starch paste has gone into the yarn or fabric and the completeness with which it has filled in the spaces between the fibers. By "coating" is meant the starch on a starched yarn that adheres to the outer portion of the yarn and surrounds it like a casing.

The fabric used for these penetration and coating studies was the same as that used in the stiffness studies. In the case of the yarns, both warp and filling yarns were raveled out from the fabric and the ends of each tied to glass stirring rods to keep them from twisting and tangling. They were then dipped in distilled water, dried, immersed in the starch paste where they were worked for one minute and left without manipulation for two more minutes. The excess paste was brushed off gently without applying pressure, and the yarns were dried under just enough tension to prevent tangling. The method followed in sizing fabrics for stiffness determinations was also used for the penetration measurements on the fabrics.

In preparing the yarns and fabric for cutting cross sections, it was necessary to mount them on cardboard frames in order to handle them better during the imbedding process. For this, frames were made as Kisser and Anderson (*13*) describe, and the yarns and fabric were placed for 12-hour periods in each of the following: 95 per cent alcohol, ether-alcohol solution, and ether-alcohol solutions of 2 per cent, 4 per cent, and 8 per cent celloidin. The samples on the frames were covered with 8 per cent celloidin in a stender dish and the celloidin allowed to thicken. The blocks of celloidin containing the samples were cut out, hardened in chloroform and double embedded in paraffin of 52° C. melting point. These double-embedded samples were then fastened to wooden blocks and kept in the cold until ready to use.

The sections were cut on a microtome to a thickness of 10 microns. They were spread and cemented to slides with the usual protein-glycerin mixture, and after drying were treated with xylol to remove the paraffin, and with ether-alcohol to remove the celloidin. The sections were stained with a dilute solution of iodine in potassium iodide and were mounted in glycerin jelly. In order to have permanent records of the sections, photomicrographs of 200 magnification were made. The photomicrographs had to be taken immediately after staining because the iodine stain fades quickly.

The warp yarns in the fabric studies were more tightly twisted and therefore more uniform in size and shape than the filling yarns. Since the construction of a yarn is a factor influencing the way starch pastes penetrate and coat yarns, it seemed that the warp yarns showed the penetration and coating more fairly than the filling yarns. Plate 2, B to G, inclusive, shows photomicrographs of cross sections of warp yarns sized with their respective starches. The dark area shows the starch stained with iodine. Although the lumens of the fibers appear dark, it is due to shadows and not to stained starch. This is evident

when one compares the pictures of starched yarns with Plate 2, A, which is a cross section of an unsized warp yarn. Plate 3, A to G, inclusive, shows the cross section of the unsized and sized filling yarns.

From direct observation with the microscope, the penetrating powers of the starches seem to follow the order of dasheen, rice, wheat, corn, canna, and potato, with dasheen starch showing greatest penetration and potato the least. Canna and wheat starches have practically equal coating powers, followed in order by corn, rice, and then dasheen. Evidently potato starch does not adhere well to cotton yarns because the yarns starched with potato did not show a coating.

Conclusions drawn concerning the order of the degree of penetrating and coating powers of the starches must be based on critical observation of the sized yarns and fabric under the microscope. It is almost impossible to make any classification from photomicrographs alone because of the difficulty of distinguishing between the shadows and the small amounts of starch penetrating the yarns. This is particularly noticeable for a starch like rice which is distributed evenly through the entire yarn. But for wheat starch, which has very uneven distribution between the fibers, photographic reproduction brings out a sharp contrast due to the well-defined dark areas. The fact that some starches show very similar penetrating and coating powers also adds to the difficulties of obtaining characteristic photomicrographs.

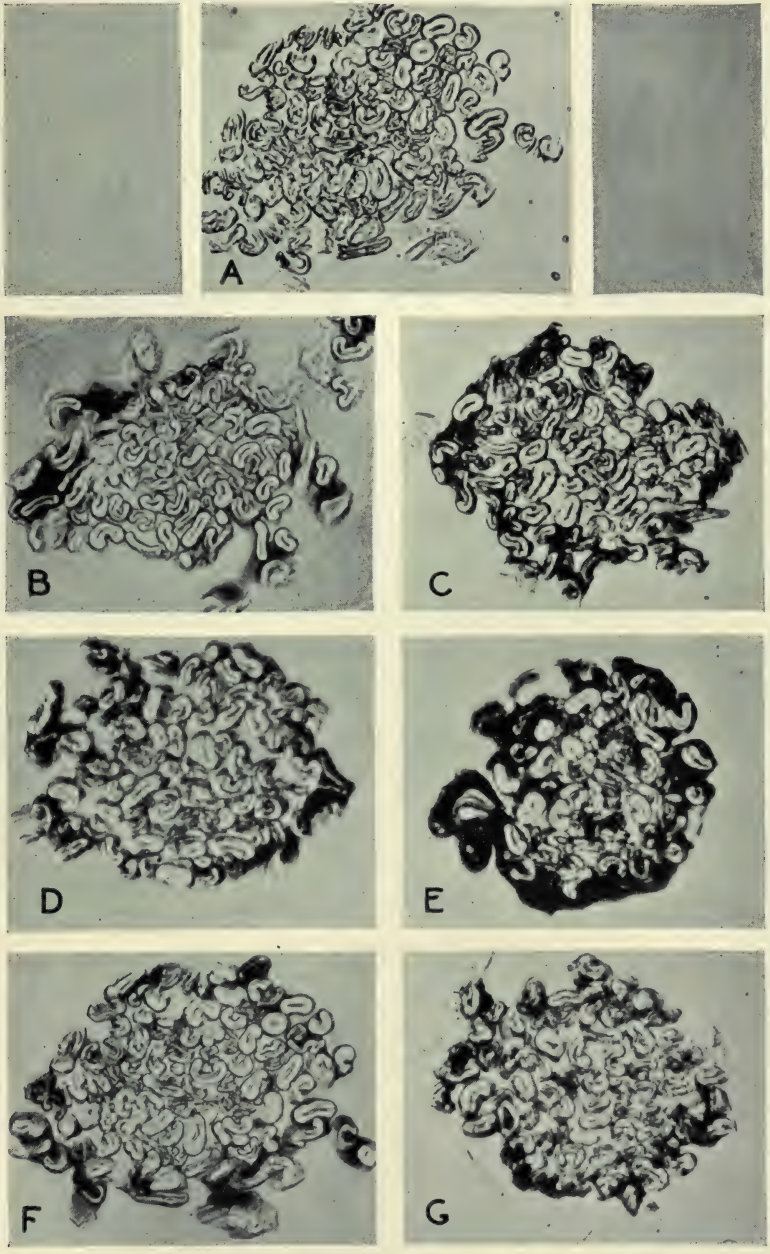
The order of the penetrating and coating powers of the starches appeared on critical examination with the microscope to be the same for the fabric as for the yarns. It therefore seemed unnecessary to include photomicrographs of the sized fabric in this bulletin.

STIFFNESS OF SIZED FABRICS

Stiffness measurements of sized fabrics were made according to the method previously developed in this division (*17*). Starch pastes of 3.7 per cent concentration were prepared, and desized fabric of the same construction as that used in the former study was sized with the starch pastes. The sample of cloth to be tested was first dipped into cold distilled water, wrung through a carefully adjusted wringer, immersed in the starch paste for three minutes, put through the wringer again, and the sized fabric then stretched on a wooden frame to dry. The most constant results were obtained when the fabric was slowly stirred during the first of the three minutes it was in the starch paste. Farrow and Jones (*5*) found in their study on sizing of cotton yarns that penetration of the size is greatly affected by the pressure and speed of the sizing machine. Therefore, great care was taken in these tests to keep the pressure and speed of the rolls constant throughout the whole series of experiments. These sized fabrics were cut into strips 2 inches wide and 8 inches long. They were then hung overnight and tested in a humidity room [6] maintained at 50 per cent relative humidity and at a temperature of 70° C.

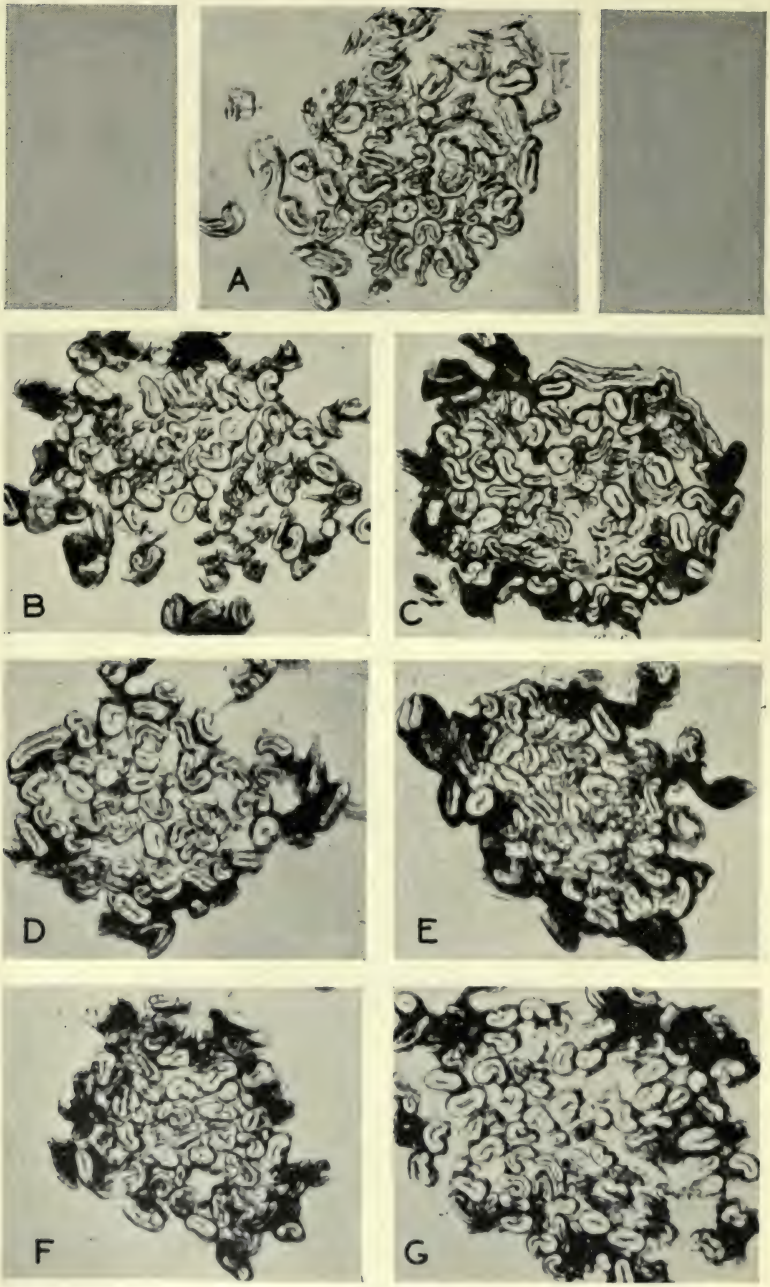
Stiffness was determined on a stiffness-testing apparatus devised by Peterson and Dantzig (*17*). The working principle of the tester depends on the deformation at an angle of 45° of a horizontally supported strip of material bending under its own weight. The apparatus consists of a vertical board provided with a metal shelf 2½

[6] The constant temperature and relative humidity room, in the Division of Tests and Technical Control of the Government Printing Office.



PHOTOMICROGRAPHS OF CROSS SECTIONS OF WARP YARNS SHOWING PENETRATING AND COATING POWERS OF STARCHES

A, Warp yarn unsized; B to G, warp yarn sized with potato starch (B); canna starch (C); corn starch (D); wheat starch (E); rice starch (F); and dasheen starch (G). All × 200.



PHOTOMICROGRAPHS OF CROSS SECTIONS OF FILLING YARNS SHOWING PENETRATING AND COATING POWERS OF STARCHES

A, Filling yarn unsized; B to G, filling yarn sized with potato starch (B); canna starch (C); corn starch (D); wheat starch (E); rice starch (F); and dasheen starch (G). All × 200.

inches wide extending from the upper corner at an inclination of 45° to the horizontal. The fabric to be tested is slowly fed through a clamp consisting of two rubber rolls mounted at the upper end of the metal shelf. In making this test, the definite position of the cloth at that point where the free end of the strip barely touches the metal shelf must be noted. Since it has been shown mathematically that projected strips of starched fabrics follow elastic laws and that their stiffness is proportional to the cube root of the elastic modulus and to the radius vector, a scale bearing these relations was made and marked on the apparatus. In this way, stiffness can be read off directly and is expressed by a value equal to 0.43 times the millimeter length of the projected fabric supporting its own weight at a 45° angle.

Peirce (*16*) has recently described an instrument, called a flexometer, which is similar in principle to the stiffness tester. This instrument makes a direct measurement of the angle through which a sample of cloth droops when a definite length is held out over an edge. The bending length and the flexural rigidity or stiffness of the fabrics tested can be obtained by simple calculation from the formulas which he has developed.

Table 8 shows the stiffness results obtained with fabrics starched with rice, wheat, corn, and potato starch as compared with those values reported previously. When the fabric was worked slowly during the first of the three minutes it was in the size, the stiffness value was slightly lower than when the fabric was worked in the size for the entire three minutes. The stiffness values for canna and dasheen starch are reported in this table for the first time.

TABLE 8.—*Stiffness produced in a fabric by starch pastes*

Starch	Determined by Peterson and Dantzig (*17*)				Determined by author							
	Fabric in paste three minutes with some stirring				Fabric in paste three minutes with stirring for one minute				Fabrics stirred in paste three minutes			
	Samples (N_1)	Mean stiffness of N_1 samples [1] (M_1)	Standard deviation (σ_1)	Coefficient of variation $\left(\frac{\sigma_1}{M_1}\right)$	Samples (N_2)	Mean stiffness of N_2 samples [1] (M_2)	Standard deviation (σ_2)	Coefficient of variation $\left(\frac{\sigma_2}{M_2}\right)$	Samples (N_3)	Mean stiffness of N_3 samples [1] (M_3)	Standard deviation (σ_3)	Coefficient of variation $\left(\frac{\sigma_3}{M_3}\right)$
	Number			*Per cent*	*Number*			*Per cent*	*Number*			*Per cent*
Potato	160	36.7	4.5	12.1	27	37.5	1.7	4.3	39	43.5	1.3	3.8
Canna					34	48.7	2.2	4.5	49	49.9	2.0	4.0
Corn	76	42.7	2.0	4.6	13	40.9	0.8	2.0	64	42.0	1.2	2.9
Wheat	160	42.8	2.7	6.3	15	41.7	0.9	2.2	35	42.5	1.1	2.6
Rice	80	42.9	2.1	4.8	15	41.1	1.0	2.4	50	42.1	1.0	2.4
Dasheen					32	47.1	1.8	3.8	26	49.3	1.5	3.0

[1] Mean stiffness of N samples expressed as 0.430×millimeter length of projected fabric supporting own weight at 45° angle.

DISCUSSION

A comparison is given in Table 9 of the stiffness of the fabric at one starch concentration with the penetrating and coating powers of the starches, the size of the swollen granules, and the consistency of the starch pastes.

TABLE 9.—*Comparison of fabric stiffness with properties of starch pastes*

Starch	Mean stiffness produced in a fabric expressed as 0.43×millimeter length of projected fabric supporting own weight at 45° angle (M)	Length of swollen starch granules: Granules measured (N_2)	Length of swollen starch granules: Average length (L_2)	Length of swollen starch granules: Standard deviation (σ)	Length of swollen starch granules: Coefficient of variation $\left(\frac{\sigma}{L_2}\right)$	Length of swollen starch granules: Average length minus standard deviation ($L_2-\sigma$)	Length of swollen starch granules: Average length plus standard deviation ($L_2+\sigma$)	Penetrating power of pastes into yarns and fabric (6=greatest penetration)	Coating power of pastes on yarns and fabric (4=greatest coating)	Paste consistency (consistometer A): Yield value (p)	Paste consistency (consistometer A): Yield shear value (j)	Paste consistency (consistometer A): Mobility (μ)
		Number	*Microns*	*Microns*	*Per cent*	*Microns*	*Microns*			*Gm. per sq. cm.*	*Dynes per sq. cm.*	*Sq. cm. per dyne-sec.*
Potato	37.5	75	324.8	113.3	34.9	211.5	438.1	1	1	10.40	87.03	1.01
Canna	48.7	75	279.9	69.5	24.8	210.4	349.4	2	4	10.60	88.70	1.25
Corn	40.9	75	59.8	13.6	22.7	46.2	73.4	3	3	9.60	80.34	6.42
Wheat	41.7	75	70.0	28.6	40.9	41.4	98.6	4	4	6.05	50.63	8.61
Rice	41.1	55	10.5	2.3	21.9	8.2	12.8	5	2	6.80	56.90	4.25
Dasheen	47.1	60	9.3	1.7	18.3	7.6	11.0	6	1	6.15	51.47	5.82

In considering first the size of the swollen granules and the penetration of the pastes, it will be noted that the order of size for the average length minus the standard deviation, $L_2-\sigma$, of the swollen granules, is the same as for the penetration of the starch pastes in the yarns and fabric. It seems, therefore, that at this concentration of starch paste, there is a definite relation between the size of the swollen granules and the penetration of the starch paste into the yarn. The swollen granules of dasheen paste are the smallest and the paste appears to penetrate most thoroughly, whereas the potato paste (largest granules) scarcely penetrates at all.

The relation between the size of swollen granules and the coating of the starches on the yarns is also shown by the fact that the average length plus the standard deviation, $L_2+\sigma$, of the swollen granules has the same order as the coating power of the starches. Since penetration and coating are almost opposite terms, it might seem that a starch paste which penetrates would not necessarily coat the yarn at the same concentration and temperature. That would be the case if the starches were composed of uniformly sized granules, but, as is shown by the coefficient of variation in length and width of the swollen grains in Table 1, the granules of some starches have a great range in size. In the case of wheat starch this coefficient of variation in length of the swollen granules is very high (40.9 per cent) which makes the average length show a range from 41.4 to 98.6 microns. The fact that wheat paste is composed of very small granules as well as large ones doubtless accounts in part for its consistency, and its penetrating and coating powers.

Although the swollen granule of canna starch is very large in size it seems to coat about the same as wheat. Potato starch, which penetrates the least of any of these starches, scarcely coats at all. Probably this is due to the fact that the swollen potato granules are very large. They are too large to penetrate, and they slough or dust off instead of adhering to the yarn. This accounts for the low stiffness in the fabric starched with potato starch. Doubtless if the potato starch would adhere and coat the yarns, the stiffness of the fabric would be greater than that obtained with canna starch.

In a general way the mobility of the paste and the coating of the yarns follow the same order, whereas yield shear value and penetration are about in the same order.

Fabrics seem to be stiffened both by starches having penetrating powers and by those having coating powers. Dasheen, which penetrates most thoroughly and coats the least of the starches studied, and canna, which has little penetrating power but coats very well, have stiffness values very nearly the same. In the case of dasheen the stiffness is due to the penetration of the starch, and in the case of canna to the coating power.

These facts are undoubtedly of importance both in the finishing of cotton fabrics in the mill and in the refinishing of them in the laundry. The selection of a starch to be used depends to a large extent on the information available as to the degree of its coating and its penetrating powers. Whether or not a starch which penetrates well or one which has high coating power is chosen depends on the type and construction of the fabric to be sized. It is hoped that the experimental data given in this bulletin will show the need for scientific information by which starches may be selected.

SUMMARY

Some physical properties of six starches and their pastes have been studied. Length and width measurements of both the raw and swollen starch granules were taken by means of a filar micrometer attachment to the microscope, consistency determinations of the starch pastes at one concentration and temperature were made by measuring their rate of flow through capillaries, and the penetrating and coating powers of the starches were determined by examining cross sections of the sized yarns and fabric. The relation between these properties of starch pastes and the stiffness in fabrics produced by the pastes was observed.

The study shows that the stiffness of a sized fabric depends on the penetrating and coating powers of starch pastes, and these factors in turn depend in a general way on the consistency of the pastes. The findings indicate also that the size of the swollen starch granules bears a definite relation to the penetrating and coating powers of the starch pastes. Further evidence is given that the consistency of starch pastes depends on the size of the swollen starch granules.

LITERATURE CITED

(1) ALSBERG, C. L.
1926. STUDIES UPON STARCH. Indus. and Engin. Chem. 18: 190–193.

(2) BARRETT, O. W.
1910. PROMISING ROOT CROPS FOR THE SOUTH. I.—YAUTIAS, TAROS AND DASHEENS. U. S. Dept. Agr., Bur. Plant Industry Bul. 164: 7–30, illus.

(3) BINGHAM, E. C.
1922. FLUIDITY AND PLASTICITY. 440 p., illus. New York.

(4) CLIBBENS, D. A., and GEAKE, A.
1928. THE MEASUREMENT OF THE FLUIDITY OF COTTON IN CUPRAMMONIUM SOLUTION. Jour. Textile Inst. 19: T77–T92, illus.

(5) FARROW, F. E., and JONES, E. H.
1927. AN EXAMINATION OF THE PROCESS OF SIZING COTTON YARNS ON AN EXPERIMENTAL TAPE FRAME. Jour. Textile Inst. 18: T1–T24, illus.

(6) ———, LOWE, G. W., and NEALE, S. M.
1928. THE FLOW OF STARCH PASTES. FLOW AT HIGH AND LOW RATES OF SHEAR. Jour. Textile Inst. 19: T18–T31, illus.

(7) ——— and NEALE, S. M.
1925. THE WETTING OF COTTON. WETTING OF RAW COTTON BY HOT STARCH PASTE. Jour. Textile Inst. 16: T209–T222, illus.

(8) GRIMSHAW, A. H.
1931. A STUDY OF THE COMPARATIVE PENETRATION OF VARIOUS SIZES ON COTTON WARPS. Melliand Textile Mo. 3: 293–295, 393–395, illus.

(9) HARRISON, W.
1911. ON SOME PROPERTIES OF STARCH RELATING TO ITS STIFFENING POWER. Jour. Soc. Dyers and Colourists 27: 84–87, illus.

(10) HERSCHEL, W. H., and BERGQUIST, C.
1921. THE CONSISTENCY OF STARCH AND DEXTRIN PASTES. Jour. Indus. and Engin. Chem. 13: 703–706, illus.

(11) ——— and BULKLEY, R.
1926. MEASUREMENT OF CONSISTENCY AS APPLIED TO RUBBER-BENZENE SOLUTIONS. Amer. Soc. Testing Materials Proc. Part II. Technical Papers 26: 621–629, illus.

(12) ——— and BULKLEY, R.
1927. CALIBRATION OF THE BURET CONSISTOMETER. Indus. and Engin. Chem. 19: 134–139, illus.

(13) KISSER, J., and ANDERSON, D. B.
1928. A METHOD OF PREPARING THIN CROSS AND LONGITUDINAL SECTIONS OF COTTON FIBERS, AND ITS IMPORTANCE IN CELL-WALL RESEARCH. Amer. Jour. Bot. 15: 437–441, illus.
(14) KRAIS, P., and GENSEL, H.
1927. DIE SCHLICHTEREI DER BAUMWOLLE. Deut. Forschungsinst. Textilindus. Dresden, Forschungsheft 7, 80 p., illus.
(15) PARKER, R. G.
1926. THE APPLICATION OF STARCH TO COTTON FIBER. Fed. Jour. 7: 712.
(16) PEIRCE, F. T.
1930. THE "HANDLE" OF CLOTH AS A MEASURABLE QUANTITY. Jour. Textile Inst. 21: T377–T416, illus.
(17) PETERSON, E. C., AND DANTZIG, T.
1929. STIFFNESS IN FABRICS PRODUCED BY DIFFERENT STARCHES AND STARCH MIXTURES AND A QUANTITATIVE METHOD FOR EVALUATING STIFFNESS. U. S. Dept. Agr. Tech. Bul. 108, 30 p., illus.
(18) REICHERT, E. T.
1913. THE DIFFERENTIATION AND SPECIFICITY OF STARCHES IN RELATION TO GENERA, SPECIES, ETC.; STEREOCHEMISTRY APPLIED TO PROTOPLASMIC PROCESSES AND PRODUCTS, AND AS A STRICTLY SCIENTIFIC BASIS FOR THE CLASSIFICATION OF PLANTS AND ANIMALS. 2 v., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 173.)
(19) RIPPERTON, J. C.
1931. PHYSICOCHEMICAL PROPERTIES OF EDIBLE CANNA AND POTATO STARCHES. Hawaii Agr. Expt. Sta. Bul. 63, 48 p., illus.
(20) ——— and GOFF, R. A.
1928. EDIBLE CANNA FOR THE WAIMEA DISTRICT OF HAWAII. Hawaii Agr. Expt. Sta. Bul. 57, 41 p., illus.
(21) SPROCKHOFF, and PARLOW.
1930. DIE ERGIEBIGKEIT GROSSER UND KLEINER KARTOFFELSTARKEKÖRNER. Ztschr. Spiritusindus. 53: 62–64, illus.
(22) TAYLOR, T. C., and BECKMANN, C. O.
1929. THE DISRUPTION OF THE CORN STARCH GRANULE AND ITS RELATION TO THE CONSTITUENT AMYLOSES. Jour. Amer. Chem. Soc. 51: 294–302.
(23) YOUNG, R. A.
1924. THE DASHEEN; A SOUTHERN ROOT CROP FOR HOME USE AND MARKET. U. S. Dept. Agr. Farmers' Bul. 1396, 35 p., illus.
(24) WALTON, R. P., ed.
1928. A COMPREHENSIVE SURVEY OF STARCH CHEMISTRY. [v. 1], illus. New York.

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TECHNICAL BULLETIN NO. 283 MARCH, 1932

TIMBER GROWING AND LOGGING PRACTICE IN THE COAST REDWOOD REGION OF CALIFORNIA

BY

S. B. SHOW
Regional Forester, California Region

INTRODUCTION BY

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Introduction by R. Y. STUART, *Forester*

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INTRODUCTION

Forestry in the United States is no longer merely a theory or a subject for discussion; it has got down to concrete things in the woods. Nor is the growing of timber confined to public lands; it is gradually making headway on land in private ownership. It is becoming an art of land management, expressed in practical measures for protecting forest growth from fire and other destructive agencies, for logging timber so as to produce a new crop of wood, and for planting forest trees on cut-over or denuded areas. The value of timber, along with other economic considerations, is causing landowners more and more widely to study the possibility of profitable reforestation. These developments have created a general demand for information on timber-growing methods which are adapted to the various types of forest growth in the United States, and what these methods will cost.

Timber culture, like the growing of farm crops, is necessarily governed in any country by the soil and climate, by the requirements of the native forest trees, and by the national economic circum-

[1] The work on which this bulletin is based was done a number of years ago at the time when extensive planting on cut-over redwood lands was beginning. The manuscript prepared for publication at that time has been revised to include new data obtained by various investigators during the last five years. Major conclusions reached in the original investigation have not been materially modified.

stances. Lessons may be drawn from the experience of other countries, as the United States has drawn upon the forestry practice of Europe, but profitable methods of growing timber, particularly under the wide range of forest types and economic conditions in the United States, can be evolved only from our own experience and investigation, region by region. Hence, to meet the demand for information on practical ways and means of growing timber profitably in the various parts of the United States, it is important that the results of our own experience and investigation to date be brought together and set forth in the clearest possible way.

This the Forest Service has attempted to do in a series of publications dealing with the 12 principal forest regions of the United States. The information presented has been gathered from many different sources, including the experience, as far as it was obtainable, of landowners who have engaged in reforestation. An effort has been made to bring together all that any agency has yet learned or demonstrated about the growing of timber in the United States; and the results have been verified as far as possible by consultation with the forest industries, State foresters, and forest schools. These publications thus undertake to set forth in a simple form what are believed to be the soundest methods of reforestation as yet developed in our common experience and study in the United States.

Necessarily, the Forest Service claims no finality for the measures proposed. Timber growing in every country has come about through a gradual evolution in industrial methods and the use of land. All too little is yet known of the best methods of growing timber under American conditions. As time goes on, research and practical experience will add greatly to the success and certainty of the measures carried out in our woods; just as American agriculture has steadily become more highly developed, or just as our manufacturing processes have been perfected through experience and study. But we know enough now about growing timber in the forest regions of the United States to go right ahead. Believing that the forest landowners of the United States are ready to consider timber growing on a large scale, the Forest Service has endeavored to place before them in concise terms the best suggestions and guides which the experience of this country to date affords.

In these publications the measures proposed for a particular forest region have been arranged in two general groups. The first includes the first steps, or the minimum measures based on local physical conditions, that are needed to prevent timber-bearing lands from becoming barren. The second group of proposed measures constitutes what may be called the desirable forestry practice in the region concerned as far as our knowledge and experience to date enable us to determine it. These measures are designed to grow reasonably complete crops of the more valuable timber trees, making full use of the real productive capacity of the land. The recommendations are addressed primarily to the landowner who wishes to use his property up to its full earning power for timber culture. As Mr. Show will make clear in this discussion of the present status of timber growing in the redwood region, redwood operators and landowners are by now fairly well committed to a policy of keeping their lands productive. In this region, therefore,

there is no great need to urge minimum measures, such as will prevent denudation of timberland. Show has rather concentrated on a common-sense résumé of the various steps involved in a policy of intensive timber growing, such as the high timber yields in this region will warrant. His bulletin has been written primarily for the landowner and operator, to whom timber growing is a concrete business and logging problem.

It is impossible for a publication necessarily dealing in broad terms with the conditions existing over a large region to attempt any brass-tack conclusions on the cost and returns of timber growing. The approximate cost of the measures advocated is indicated as far as practicable and the extent to which they may be of benefit in connection with logging operations, but no attempt is made to segregate the items chargeable to harvesting one crop of timber from those which should be regarded as invested in a following crop. Conservative estimates of the future yields of timber that may be expected under the various practices recommended are given where the facts available appear to warrant them; but no forecasts of the profits to be derived from commercial reforestation are attempted. The financial aspects of forestry can not be dealt with in general terms. Here again expert advice must deal with the situation and with the problems of the individual forest owner or manufacturer.

As a broad conclusion, however, with the exception of limited situations which are dealt with region by region, the Forest Service has tremendous faith in the commercial promise of timber growing to American landowners. In the long-time pull, the law of supply and demand will work to create timber values which in large portions of the United States will pay fair returns on forestry as a business. The economic history of other countries that have passed through a cycle of virgin-forest depletion similar to that which the United States is now traversing points to the same inevitable conclusion. The time is fast approaching when forestry, and forestry alone, will supply the enormous quantities of wood demanded by American markets. The fundamental laws of business must in the nature of things so operate as to enable the markets of forest products to be supplied at a profit to the grower of timber. The returns already being obtained from this form of land employment at many points in the eastern United States show plainly enough that this relationship between the value of timber and the cost of producing it is already coming about to a marked degree.

To the men who own forest-producing land in the United States, or are engaged in industries which require raw material, forestry now, barring periods of wide-spread depression, offers a commercial opportunity in many localities. Satisfactory returns from forestry can not be promised in sweeping terms any more than returns from the manufacture of lumber or paper. But the opportunity for a profitable employment of capital and business talent in the growing of timber merits the same consideration and the same expert guidance as industrial opportunities in the conversion of timber. This applies with special force to the commercial institutions in the United States which have made large capital investments in manufacturing plants and distributing organizations, dependent for their mainte-

nance upon a future supply of forest-grown material. It applies equally to the owners of land in large tracts or farm wood lots, the earning capacity of which lies solely in the growing of trees, and which without tree growth will become either a doubtful asset or an outright liability.

During a period of pronounced depression, it is natural that new ventures, such as systematic timber-growing, should be accepted slowly by lumbermen. In this respect the lumber industry does not differ from other major industries. The imperative business need at such a time is for curtailment of expenditure, rather than expansion. The current condition of the forestry enterprise in the redwood region reflects this necessity. But it is doubtful whether the vigor of the forestry program already under way will be permanently blighted. Rather it is to be expected that a careful appraisal of methods previously used will be made and new methods offering promising possibilities will be studied.

The fundamentals necessary for successful forestry ventures by private owners remain unchanged—rapid growth, intrinsically valuable species, and accessibility to permanent markets. The means suggested in this bulletin for capitalizing these fundamentals are deserving of study and test by the individual landowner. Timber-growing practices in the redwood region have not yet been tested for a long enough time to justify broad and categorical conclusions. The need still exists for trying a variety of methods, and studying carefully just what each accomplishes. Some degree of uncertainty regarding the exact outcome of each method should not, however, obscure the basic fact that positive attention to timber growing will undoubtedly yield positive returns that would not otherwise be obtained.

The redwood region, moreover, still has such large areas and volumes of virgin stumpage, that abundant opportunity remains to place the industry as a whole on a sustained-yield basis, without curtailment of existing cut. This fortunate fact further adds to the attractiveness of the private-forestry venture.

The Forest Service earnestly asks the forest landowners of the United States to determine for themselves, with the same care with which they would approach any other business problem, whether timber growing does not offer a commercial opportunity which should be grasped. It commends this series of publications to them, not as a complete or authoritative scheme that can forthwith be followed with profit in their own woods, but as a starting point in utilizing the opportunities that forestry may hold out.

R. Y. Stuart.

STATUS OF TIMBER GROWING IN THE REDWOOD REGION

Decided progress has already been made in timber growing in the redwood region. Operators have carried the practice much further there than in most other regions in the country (*9*).[2] The chief reason is that the soil and climate and the characteristics of the principal tree of the region all favor rapid growth and large yields of timber.

[2] Italic numbers in parentheses refer to Literature Cited, p. 21.

As logging has progressed and the area of virgin forests diminished, redwood operators, like operators in other regions, have recognized that they were becoming to an ever-increasing extent holders of cut-over land, and engaged in what might be called "the cut-over-land business." That is, they were acquiring as a by-product of the lumber-producing business a great deal of land producing no immediate revenue and potentially of value chiefly, and in many instances solely, for forest growing. They found, however, that, except in instances of unusual abuse, their cut-over land would renew its growth of redwood to an appreciable extent and in a remarkably short period of time without any assistance from them. If an owner wished to invest in a second timber crop, the cut-over land would go at times as much as a third of the way with him, leaving but two-thirds of an extremely quick and profitable crop dependent upon his own efforts.

This situation, as long ago as 1920, induced a number of operators to investigate the possibilities of profitable timber growing, including the advisability of trying to obtain fully stocked stands of second growth, and the chances of being able to incorporate their cut-over lands in a system of continuous timber production and permanent logging operation. They found that, although much basic information was and is lacking regarding the redwoods and associated species, the more immediately important silvicultural facts were fairly self-evident, or at least were discernible after short study; and on the strength of these data they did not hesitate to make plans involving considerable investments in the growing of future timber crops.

By 1922, the redwood operators were, as a group, committed to the handling of their cut-over lands for fairly continuous timber production.[3] Owners representing about 70 per cent of the production had by that date started definitely to restock and to protect their lands, in the endeavor to obtain full stands of young growth and to remain permanently in the lumber business. The forestry program took the form of planting, plus fire control, on cut-over areas. For a number of years, until about 1928, the output of the several large redwood nurseries ran up to several million trees a year, and during that time approximately 25,000 acres of old and new cut-over land were planted (*12*).

From 1928 to 1931 financial depression and possibly other factors caused a substantial curtailment of planting operations. In addition, the economic depression of 1930–31 compelled the operators to give attention to improvement of logging methods and resulted in detailed studies of logging costs. In these studies the primary purpose was to determine what trees and logs are handled at a profit, or at least at no loss, and to increase the net return from lumber through changes in cutting and log-selection practices.

The detailed results of these studies are not yet available, but apparently they follow the general pattern of similar investigations in other forest regions, indicating the economic undesirability of cutting the smaller trees. A change of cutting practice to leave such

[3] In a mimeographed report entitled "California Redwood," circulated in 1922 by six lumber companies in the redwood region.

trees will, of course, automatically introduce a form of selection cutting including the leaving of many more seed trees than heretofore.

With the excellent yields possible in the region, there can be little question that intensive timber growing to produce full timber crops will be more profitable than any halfway measures. And this appears to be the present common understanding among the operators. The adoption of definite plans for reforestation with the principal emphasis on planting, the employment of foresters to direct such work, and actual planting on a considerable scale—all point to an intention to strive for the greatest possible return from the investment.

While concentrating, however, on methods and practices to keep cut-over lands fully productive, the industry has not on the whole given enough attention to the other half of a complete forestry program—the adjustment of annual cut to what the land can be expected to produce. Systematic planning for sustained yield is just as necessary in the long run as is the commendable attention given by the industry to the condition of cut-over lands.

The emphasis of this bulletin will be laid on the measures necessary to obtain full timber crops in the redwood region, taking into consideration the chief characteristics of the region and its forests, and the condition of the forest lands as a result of past and present methods of handling them. Much information of importance to the operators is yet to be gathered; the endeavor here will be to present all that is available and to define as completely as possible the lines of further research that must be followed by private and public agencies as rapidly as opportunities are presented.[4]

CHARACTERISTICS OF THE REGION AND FORESTS

The redwood region is a narrow, irregular strip along the Pacific coast, running from Del Norte County, near the Oregon State line, southward through Humboldt, Mendocino, Sonoma, Marin, San Mateo, and Santa Cruz Counties to a point some distance south of San Francisco Bay, where it finally pinches out. This is a region of frequent fogs and favorable soil; and, indeed, its breadth of 35 miles and less is sharply defined throughout, on the east by the ridges that stop the ocean fogs, and on the west by the sandy soil of the immediate coast line, where redwood and its associates will not grow.

The original redwood area, according to Forest Service estimates, was 1,454,000 acres, of which, by 1925, 543,000 acres had been cut over, leaving 911,000 acres of virgin timber. Of the cut-over land, about 143,000 acres has been put to agricultural use or has been denuded. Approximately 400,000 acres is producing timber in some degree (*8*).[5]

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[4] Acknowledgment is made to Donald Bruce and Woodbridge Metcalf, formerly professors in the University of California Forest School, to Emanuel Fritz, professor in that school, and to D. T. Mason, consulting forest engineer, for many of the data employed in this bulletin. Their findings are in all instances corroborated by research of members of the Forest Service.

[5] The reference in this instance is to an independent estimate made by Mason in 1922, which placed the remaining area of virgin forest at 960,000 acres, and the total virgin stand at 60,000,000,000 feet, board measure, of which 50,000,000,000 was redwood. An independent determination of cut-over areas by A. N. Weber (1925) places the total at 427,810 acres, but this does not apparently include all of the area of cut-over land that has been cleared for agricultural use. The same author gives 841,251 acres as the total of virgin timber left in Del Norte, Humboldt, Mendocino, and Sonoma Counties in 1925.

The average rate of cutting up to 1925 was about 600,000,000 board feet a year, representing 10,000 acres of mature forest. The indications are that this output will not be rapidly increased, and it is accordingly estimated that many of the operators have a sufficient reserve of merchantable timber to last 40 to 50 years, or until second growth becomes large enough to cut. Also, there are several large holdings on which operations have not yet started. Conditions in the region are in fact extremely favorable for intensive timber growing as a definite part of a permanent timber business.

COMPOSITION OF THE FORESTS

For the purposes of this bulletin the redwood type and the redwood region are held to be identical, and distinctions in treatment because of type differences are regarded as unnecessary. The virgin redwood forests show, however, a considerable variety in composition. Generally, redwood (*Sequoia sempervirens*) is mixed with other species, including Douglas fir (*Pseudotsuga taxifolia*), lowland fir (*Abies grandis*), Sitka spruce (*Picea sitchensis*), and western hemlock (*Tsuga heterophylla*) as the most important conifers; and tanbark oak (*Lithocarpus densiflora*), California-laurel (*Umbellularia californica*), and red alder (*Alnus rubra*) as the most important hardwoods.

Redwood is rarely found in pure stands, save on those partially stocked cut-over lands where powerful logging machinery and repeated fires have destroyed all seed trees of Douglas fir and associated species.

Douglas fir occurs throughout the entire region as the principal associate of redwood, gradually increasing in importance at greater distances from the coast, until on the eastern edge of the redwood belt it becomes the principal species and the forest type changes to Douglas fir with only an occasional redwood.

Lowland fir and hemlock, absent in the southern portions of the range, are of considerable importance in Mendocino, Humboldt, and Del Norte Counties, and Sitka spruce is important in the last two counties. Here pure stands of Douglas fir or of spruce, or of the two in mixture, are not uncommon. In the sandy soil of the immediate coast pure stands of Bishop pine (*Pinus muricata*) prevail.

Next in importance to the associated softwoods is tanbark oak, a hardwood of established value as a source of tanning material. Tanbark oak will be present in the new forests, for it has sprouting ability, but whether to the extent of being a material factor in raising the degree of stocking on intensively managed cut-over lands is as yet uncertain. The prejudice among operators generally against second-growth tanbark oak is almost certain to be removed in time, for with the disappearance of eastern chestnut, which has furnished over half of the domestic tanning material, tanbark oak will offer new possibilities. Experiments by the Forest Products Laboratory prove the technical qualities of the wood to be high and the obstacles to its proper seasoning to be by no means insurmountable.

YIELD CAPACITY OF REDWOOD LANDS

The opportunities for private timber growing in any region depend above all on the growth rate, and in this respect the redwood lands

are exceptional. Redwood at an early age reaches a size which is considered merchantable in most forest regions. On Site I (the best sites) at 20 years of age the average redwood is 8 inches in diameter and 51 feet high. On Site II (good sites) at 25 years of age the average tree is 9 inches in diameter and 53 feet high. At this rate of growth the probable cutting rotation for the redwood timber crop will usually be 50 years or less. Within 50 years a satisfactory merchantable forest will be produced. Moreover, the wood, though consisting largely of common lumber and railroad ties, will be comparable in quality to similar grades from old-growth timber. Short rotations are anticipated at first because of the financial desirability of an early second cut. As land policies are worked out, however, the probable tendency will be to hold stands longer for the quality and price increment.

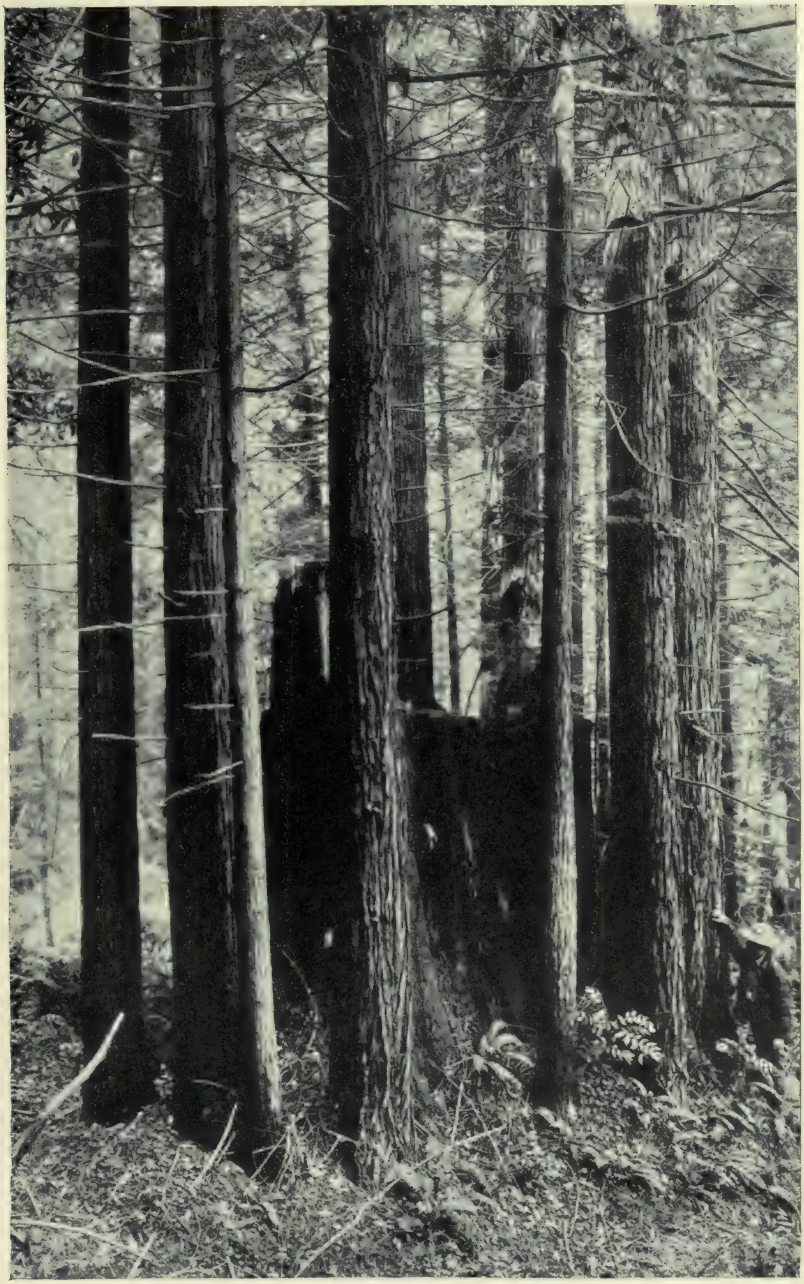
The yields of fully stocked forests in this region (*2*) exceed anything known among other American conifers, even surpassing the Douglas fir of the Northwest (*7*). At 50 years of age the yield of full stands of second-growth timber is 116,000 board feet per acre on the best sites (Site I). This is the estimate by the Clark international rule, which gives 95,000 board feet to the acre on good sites (Site II) and 76,000 feet on medium sites (Site III). A mill tally of the trees from a typical second-growth stand shows that by careful sawing these yields can be attained to within 3 or 4 per cent. Even if measured by the Scribner decimal C rule, which underruns seriously when applied to small timber, the indicated yields at 50 years of age for these three sites would be not less than 80,000, 65,000, and 50,000 board feet to the acre, respectively.

Poor sites (Sites IV and V) probably occur here and there, but most of the region is rated as Site II or III.

Because of the ability of redwood to sprout, the minimum stand obtained after cutting is not less than 25 per cent complete, except where repeated fires have occurred. (Pl. 1.) Often the stand is as much as 35 per cent complete. Such a stand will cut 20,000 to 35,000 board feet an acre at 50 years. Associated species, except hemlock, grow as rapidly as redwood, at least up to 50 or 60 years, and where seed trees of such species as Douglas fir are left to seed in part of the cut-over land, stands from 60 to 80 per cent complete can be counted on to yield 45,000 to 80,000 board feet per acre. Indeed, mixed second-growth stands commonly yield as great a cut as do pure redwood forests. Even pure stands of Douglas fir in the redwood region produce as much lumber as does redwood. In utilizing fully the remarkable growing capacity of the forest land, pure or mixed stands are equally valuable.

Although the virgin redwood forest is commonly said to be thousands of years old, nothing is further from the fact (*4*). On the contrary, the forest is many aged, approaching a true selection forest in character. On one 30-acre plot, for example, the following very wide range of ages above 200 years was found:

Age class	Number of trees	Age class	Number of trees
201 to 300 years	108	701 to 800 years	38
301 to 400 years	89	801 to 900 years	34
401 to 500 years	81	901 to 1,000 years	31
501 to 600 years	102	More than 1,000 years	17
601 to 700 years	67		



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REDWOOD SPROUTS ASSURE PARTIAL REFORESTATION

Sprouts bring an element of hope for new stands of timber. Groups of redwood sprouts such as this surround the parent stumps and their rapid growth soon makes it evident that partial restocking is assured. Within 40 or 50 years after the virgin forest is cut, provided fire is kept out, a partly stocked forest will be ready for the ax. The main immediate problem of timber growing in the redwoods is to supplement this sprout forest with other trees of valuable species, either by planting or natural reproduction. Only thus can a full timber crop be obtained from the land.

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THREE CHAPTERS IN THE STORY OF REDWOOD REGENERATION UNDER PRESENT CUTTING CONDITIONS

A, In accordance with custom the trees have been felled and the area broadcast burned before skidding; all young trees have been destroyed; redwood sprouts will appear in scattered clumps but other species grown from seed will be absent; the result will be far below the yield of the dense virgin forest shown in the background. B, The area under skidding shows little promise for the future; in spite of the desolation caused by the slash fires a quantity of débris remains as fuel for later fires. C, Finally the scattered clumps of redwood sprouts reclaim the land, but unaided will yield something less than one-third of the possible timber harvest; the planting crew is filling in the larger gaps with planted redwood; the result will be a single-species, limited-use crop that is little justified either silviculturally or commercially.

As a forest, the typical virgin redwood stand is not overmature, but has a wide representation of age and size classes. It is in fact a true selection forest. Because of this fact, and because of the ability of redwood to live and to continue growth to a great age, the redwood selection forest appears to afford a natural and inviting opportunity for some form of selection cutting.

IMPORTANT FACTS ABOUT NATURAL REPRODUCTION

The basic facts about natural reproduction in the coast redwood region of California may be briefly summarized as follows:

Advance reproduction is not a factor in restocking cut-over redwood lands; the new forests, both of redwood and associated species, start after logging.

Redwood sprouts from the stump when cut at any season of the year. In most cases the sprouting ability is not lost even in extreme old age. Redwood stumps sprout repeatedly if the sprouts are killed back, though this ability may in time be lost.

Redwood reproduction from root suckers is not of material importance on the slopes, which constitute probably over 90 per cent of the present timbered area of the region.

Except on moist flats constituting only a small percentage of the total area, extensive fully stocked second-growth stands of pure sprout redwood do not and will not occur. As has already been stated, sprout stands of redwood under favorable conditions average from 25 to 35 per cent fully stocked.

Redwood bears seed abundantly, but seedling reproduction is found only under a very narrow range of conditions, such as the combination of fresh mineral soil on cut-over and burned-over lands near a cutting edge; that is, where virgin timber adjacent to cut-over lands has afforded protection. On most cut-over areas examined all redwood second growth was obviously from sprouts.

On the contrary, Douglas fir reproduction from seed is equally and widely distributed; and, because of the ample moisture, mortality of seedlings is low. Apparently this reproduction comes from seed trees remaining after the logging operation. Examination of many cut-over areas has revealed reproduction from seed trees now alive as well as from trees which were wind-thrown some years after logging. This reproduction is sometimes as far as one-quarter of a mile from the seed trees.

EFFECTS OF PAST AND CURRENT TREATMENT OF FOREST LAND

CUT-OVER LAND

Until about 1919 little attention was paid to cut-over land as being in any sense forest land. Indeed, throughout the history of redwood logging, cut-over lands have been regarded both by lumber companies and by ranchers as potential farm or grazing lands, chiefly valuable for anything but timber production. This attitude was evident in repeated burning to prevent perpetuation of the forest.

Certain areas originally heavily timbered with spruce, chiefly flats or rolling lands along the coast, have been turned into profitable farm lands of high quality, and on the redwood slopes much feed has been raised on cut-over lands. Such success has encouraged

attempts at more general exploitation of these lands, and it has been characteristic for operators in the past to sow grass seed on cut-over lands immediately after yarding was completed. Excellent feed for stock for a few years was thus obtained, but within two years after logging brush usually appeared and spread rapidly. Such areas were frequently reburned in a fruitless attempt to control the brush.

It has become evident that the redwood region, unlike the pine region, does not take kindly to grazing land and timber production on the same areas. Grazing soon becomes impossible if cut-over lands are protected from fire, and the burning that is intended to make grazing possible wipes out reproduction of all nonsprouting species and frequently destroys also the source of the seed. Burning has also had the effect of inducing erosion, which in turn has probably reduced soil fertility and the rate of growth of new forests. Thousands of acres of the older cut-over redwood lands which were burned after logging are covered with a dense stand of brush and have but 15 to 35 per cent of a full stand of redwood.

The significant fact for redwood-land owners is that their property, except for a negligible area of deep-soil flats, has a greater value for timber growing than for any agricultural use. The cost of seeding cut-over lands for grazing varies from $3 to more than $10 per acre, with an average of about $6. The amount of feed obtained thereby is relatively small, and the practice represents a low type of agriculture.

A study by A. N. Weber (1925) showed that on an average it required 35.4 acres of cut-over land to furnish grazing for one cow for one year. The average annual rental value for grazing is only from $0.09 to $0.15 per acre per year. The carrying capacity for sheep was found to be one head to 3 to 5 acres.

W. T. Clarke, of the University of California College of Agriculture, after an intensive study of the agricultural possibilities in this region (*3, p. 185*) says:

> There are serious handicaps to successful agriculture in cut-over redwood lands. These handicaps are so great that in a very large portion of the area the use of the lands for ordinary agricultural purposes would be an economic blunder.

He says also (*3, p. 186*): "The farmer of such lands will meet many extraordinary difficulties not present in ordinary unforested agricultural sections."

In support of such statements is the fact that clearing these lands of brush and stumps has cost up to $400 an acre, and the clearing of stumps up to 2 feet in diameter has cost $150 an acre. Very little land in the region, in Clarke's opinion, can possibly justify such expenditures.

That such facts are now appreciated is evident in the operators' efforts to grow timber on the land left after logging. With the adoption of plans for restocking these acres, operators have generally abandoned the old traditions of repeated burning after logging.

LOGGING AND SLASH DISPOSAL

Except locally and in the early days, machinery has been used almost entirely in logging in the redwood region. The extraor-

dinary size of the timber and the steepness of the country except the relatively small flats along streams and near the coast have both made power logging necessary.

As in the pine region, logging engines have developed rapidly in the evolution of power and line speed, and several new methods of logging have been extensively used, particularly in recent years. The high-lead method, in which the main lead block is placed on a spar tree up to 200 feet high, is commonly employed. Several variations of the sky-line method, such as that in which logs are transported by an underslung trolley on a fixed line anchored high above the ground at both ends, are also in use. More recently the caterpillar tractor has been used in yarding.

The general practice is to clear-cut redwood and to leave much of the Douglas fir and most of the white fir standing. Cutting of these other species varies with market conditions. Usually some of the uncut trees are smashed in falling the redwoods, and others in yarding. Those that escape are a valuable source of seed if they can be saved through later steps in logging. It is probable that the systems of yarding now in use need not in any instance be fatal to seed production on these areas, if reasonable care is exercised in the conduct of the operation. It is doubtful if falling and yarding at their worst are ever so destructive to the seed trees as is the general custom of slash disposal.

Timber is felled usually months, and often a year or more, in advance of yarding. In current practice, after falling and limbing are completed, most companies peel the logs and then fire the enormous accumulations of bark, limbs, and tops while the logs are still on the ground. (Pl. 2.) This practice results in serious loss of merchantable material, for much of the sapwood and big chunks of shattered but merchantable logs are burned. The loss is placed by competent observers at 15 to 40 per cent of all merchantable material, averaging 25 per cent. The delay in yarding commonly results in serious deterioration of the sapwood of the Douglas fir, amounting in many cases to unmerchantability.

In addition to the loss in merchantable timber must be reckoned the Douglas fir trees which would have survived falling and yarding. Many of these and sometimes all are killed by the slash fires, which are commonly set at the foot of slopes and spread uphill with terrific heat. These fires seem to be employed in most instances to an unnecessary degree, and in a needlessly destructive manner. Nor are they entirely effective, for a very large accumulation of débris remains on the ground after yarding, offering fuel for subsequent fires.

In a few instances an effort has been made to improve on these practices. On some operations the burning is done before peeling, in order that the bark may protect the wood. This is preferable in that there is less actual loss of timber; but some loss is still evident, and the damage to seed trees is of course the same. Only one operation has been noted so far on which an effort has been made to yard without burning (*5*). In general it may be said that the current logging methods, though efficient in getting logs out cheaply, frequently leave so few seed trees that full or nearly full stands of new growth can not be expected without planting.

The development of a process, now about to be put on the market, for the manufacture of pressed board and insulation board from redwood bark will change radically the apparent need for wholesale slash burning. To use the bark most efficiently it must be brought to the mill on the log, and fire must be kept out of the woods prior to yarding.

Caterpillar tractors have recently been employed in conjunction with donkey engines in the region, and the results give some indication that logging costs can be reduced materially thereby. If further study proves such reductions to be possible, the result may be to decrease the apparent need for wholesale use of fire in advance of yarding.

MEASURES NECESSARY TO PRODUCE FULL TIMBER CROPS

Many phases of intensive timber growing for full crops demand more study than it has as yet been possible to give them. These include consideration of how to complete the open and scattered stands on the older cuttings when dense brush has come in; whether to work for pure stands of second-growth redwood, or for mixed stands of redwood, fir, and spruce; and how to handle the valuable tanbark oak in the new forest, both as a source of tanning material and for lumber. All these require answers in the near future.

It is, however, already obvious that, to capitalize fully the remarkable productive capacity of the redwood lands and to obtain full stands promptly after logging, the landowner must take active measures to assist the natural processes of reforestation. Also, the general outline of the measures necessary is not difficult to trace.

As has been shown, young growth required to complete redwood stands can be obtained by saving seed trees of associated species, by planting with nursery stock, or by a combination of the two methods. Planting is the solution generally favored by the redwood operators; but the alternative possibility of saving the needed seed trees through more careful logging operation and protection from fire is attractive, because of the possibility of much lower cost.

FULL STANDS BY PLANTING

As a means of closing the gap between the partial forests which follow current logging methods and the complete stands which give the largest return to the operator, planting is the method which has been given the most thorough test.

In deciding whether the safer course is to use redwood as the principal planting species and so to develop large areas of nearly pure redwood, or to employ fir and spruce as well and so to continue the present mixed stands, the experience of other countries may be a guide. Experience with spruce in Saxony indicates how disastrous may be the results of creating pure stands on the lands formerly occupied by mixed forests. Wholly unanticipated disasters from insects and diseases have overtaken such artificial forests, and an even more unfortunate result has been that the soil itself has deteriorated to a serious degree. Although it is only by experience that the future of extensive pure stands of redwood in this country can be determined, the results abroad at least indicate the need for caution. Another consideration of interest to the operator is that redwood lumber is

not suited for all uses and that Douglas fir is a general utility species. By continuing to produce fir, the redwood operator will avoid the dangers of a single-crop market.

In the long run, it would appear that fairly high percentages of Douglas fir, spruce, and lowland fir can well be retained in mixture with second-growth redwood. All are valuable, and the possible dangers of disaster to pure stands are sufficiently great to be seriously considered. Port Orford cedar, western red cedar, and California-nutmeg should also be tested; likewise, the possibility and desirability of growing hardwoods, particularly tanbark oak, as an integral part of the new forests.

The technic of raising nursery stock and of planting in the redwood region, although not yet completely worked out, has had the advantage of considerable preliminary work (*11*). Further, the results of eight years of experience with large-scale planting (*12*)[6] now give a fair indication of the costs of planting and of survival under different conditions. The comprehensive data obtained by the Forest Service in the Douglas fir region are also available and may in large measure be applicable in the redwood region (*6*).

In large-scale redwood plantations about 500 trees per acre on an average are set out, the range being from 350 to 740. The average costs of planting stock are: For 1–0 stock, $7.50 per M; for 2–0 stock, $9; for 1–1 stock, $10. Some companies have used seedling stock (1–0) almost entirely; others have used all or principally transplant stock (1–1).

Planting labor cost has varied from $2 to $3.50 per acre, the average output per man-day varying from 400 to 800 trees, depending on the class of stock and the character of planting area. Additional costs of $2.50 per acre, including supervision, surveying, preparation of area, and overhead, bring the total cost per acre to $7.50 to $10. Those who have handled the large-scale jobs believe some further reductions in costs are possible.

Survival of different plantations of redwood has varied greatly, depending on numerous factors. The more important causes of death of planted stock (*12*) have been given as:

	Per cent
Poor stock and poor planting	10
Rodents	10
Grazing animals	20
Soil, site, drought	25
Root competition and shading	35

The average survival over a period of seven years in the study made by Gibbs was 67 per cent, and in Schofield's study, 50 per cent. The survival varies somewhat from year to year, depending principally on amount and distribution of rainfall.

Survival on south slopes has proven rather uncertain, and some plantations have been failures. Gibbs reports that the average survival on south slopes over a period of seven years was 54 per cent and 62 per cent for 1–0 and 1–1 redwood stock, respectively, and 76 and 84 per cent on the north slopes. An average survival of 50 per cent, if it can be attained consistently and based on planting 500 trees per acre, should give a fair and reasonably full stand.

[6] In addition to Schofield's work the writer had access to a manuscript report of a similar study (1931) by W. H. Gibbs on redwood reforestation by the Caspar Lumber Co.

Another study showed that on south slopes the percentage survival of thrifty redwood trees planted in the open was from 0 to 22 per cent of the total set out; the corresponding figures, where the trees were set so that they received some shade from the south, east, and west, were 70 to 90 per cent. This finding of the extreme importance of some protection to the individual plant on the more difficult sites is in close harmony with planting experience in the California pine region.

The same study showed that on north slopes the survival without individual shade was 63 per cent; with shade from three sides, 90 per cent. No detailed data are available on relative survival when planting was done soon after logging, as compared to planting older cuttings on which brush was thoroughly established. The table of causes of loss given above indicates that root competition and shading are the most important causes of loss. It seems evident that planting of the older cut-over lands, largely occupied by heavy stands of brush, is a problem of considerable difficulty, comparable with brush-field planting in the Sierra region.

Experience has also shown (*12*) that areas of thin and rocky soil, originally bearing a relatively light stand of timber, will encourage little or no survival.

Experiments (*12*) in planting other conifers native to the region (Douglas fir, Sitka spruce, Port Orford cedar) resulted in survival generally comparable with that of redwood. On most sites there is no apparent necessity for planting redwood alone.

It has been found that several years must elapse after planting before trees become thoroughly established and begin rapid height growth. Sprouts, of course, grow rapidly from the very start. In all probability the yields from stands containing a high percentage of planted stock will be lower at a given age than where the trees originated from sprouts (*1*). At 50 years of age, the volume per acre of stands from seedlings is 74 per cent that of sprouts. Experience does not yet indicate whether improper setting of the trees in the hole will have the serious aftereffects that have developed in other forest regions.

Further research in methods of growing and planting forest trees in the region is needed. In particular the early plantations should be watched carefully for years to determine the loss rate under different methods of planting, the relative vigor and rate of growth of young trees grown from seed of different sources, and the effect of spacing in plantations. Improper planting may have far-reaching consequences, and no effort should be spared to develop practices as nearly correct as possible at the very beginning of extensive planting.

FULL STANDS FROM NATURAL REPRODUCTION

Enough has already been said regarding the value of associated species in the redwood region to indicate the desirability, and often the necessity, of leaving seed trees of these nonsprouting species, especially of Douglas fir, when the redwood is clear cut. Even if it is planned to plant redwood to fill in the blanks in the new forest, reservation and preservation of seed trees of the other species are probably just as important as though no planting at all were in-

tended. The more natural reproduction thus obtained, the less expense will be necessary for planting, and the more generally will mixed stands prevail. Adjustment of cutting practice to this end is no difficult matter.

Little investigation is needed to show that an average of even one Douglas fir seed tree to an acre of cut-over land may add as many trees to the new forest as will sprout from redwood stumps. Two or three trees to an acre reserved from and left intact by the logging operation should accordingly be sufficient in most instances to insure approximately complete stocking. Even now, when Douglas fir and associated species are cut nearly as clean as the redwood, it is usually true that a number of small trees or of very large defective trees, such as might be suitable for seed trees, are passed by. In many instances these alone would be sufficient to seed the area satisfactorily.

The saving of seed trees therefore appears to be practicable, provided some degree of care is exercised in falling, yarding, and slash burning. It is never likely to prove very costly. The result will make all the difference between a natural stand of redwood alone, at best 25 to 35 per cent complete, and a mixed stand 80 per cent or more complete. What planting may still be needed to get full stands in some instances will be very much less than if no seed trees were left to aid in reforesting the cut-over land.

Naturally, groups of seed trees are more effective than isolated individuals, and are less subject to windthrow, which must be recognized as an ever-present threat to scattered trees.

THE CONTROL OF FIRE

Until planting technic has been completely worked out, systematic fire protection is the prime essential to improve the condition of the older cut-over areas. (Pl. 3.) Such protection presents unusual difficulties in this region, however, because of the well-established custom of burning over the logged-off land and the general opinion of many local people that cut-over land is valuable rather for grazing than for timber growing. The systematic protection of these lands against fire, beginning immediately after the completion of yarding, involves not only the development of an organization for putting out fires, but also recognition of the primary value of cut-over lands for growing timber and the correction of the existing local habit of thought upon this subject. Continued and systematic law enforcement and education are essential parts of the fire-protection program, and only as these are included can there be hope for a reduction in the number of fires. Before the burning and reburning of cut-over lands will be successfully checked, public opinion must accept the fact that growing timber is a more profitable use of the land than grazing and that fire is hostile to that use.

Public education, an adequate general protection system, and special protection measures are all of them important, whether the cut-over lands are to be planted or are to be restocked by natural reproduction of associated species. Next in importance perhaps to public education is general protection, and toward this substantial advances have already been made by the redwood operators.

THE GENERAL FIRE-PROTECTION SYSTEM

The first organized protection work in the redwood region was undertaken by the Mendocino County Redwood Fire Protective Association, which since 1912 has protected about 75,000 acres of virgin timber. The State division of forestry, within the past few years, has built up a force of 25 rangers, lookouts, and fire guards in the redwood counties and has made considerable progress in organizing an effective system of protection on both virgin forests and cut-over lands. Several individual lumber companies as well have initiated systematic protection. Undoubtedly, now that a land policy is decided on, systematic protection will be extended, probably by a cooperative State and private-owner combination, aided possibly by Federal contributions made under the Clarke-McNary law. At present, protection on both virgin forest and cut-over land is generally below the needs of the region.

Because of the limited experience in the region, neither the necessary degree of protection nor its cost is known with exactness. In the virgin forest, where fires spread less rapidly than in the pine region, an organization capable of putting suppression forces on fires within 1½ to 2 hours after the discovery of fire—or what is termed 1½ to 2 hour control—will be ample to keep the burned area at a low figure, at an annual expenditure of about 2 cents an acre each year. Direct protection such as this can be obtained by the installation of additional lookouts, the building of new telephone lines, roads, and trails, the employment of more fire guards, and the active aid of woods foremen in reporting and suppressing fires. For this purpose the type of organization developed on the national forests in California can well be employed, unless study and experience demonstrate that mobile patrols are superior.

For cut-over lands, until the new stands are at least 20 to 30 years old, intensity of protection should be doubled. In practice the virgin and second-growth forests can not always be handled separately and, with large areas of cut-over land accumulating, the annual cost for all forests will be nearer 4 than 2 cents an acre.

CARE WITH FIRE IN LOGGING

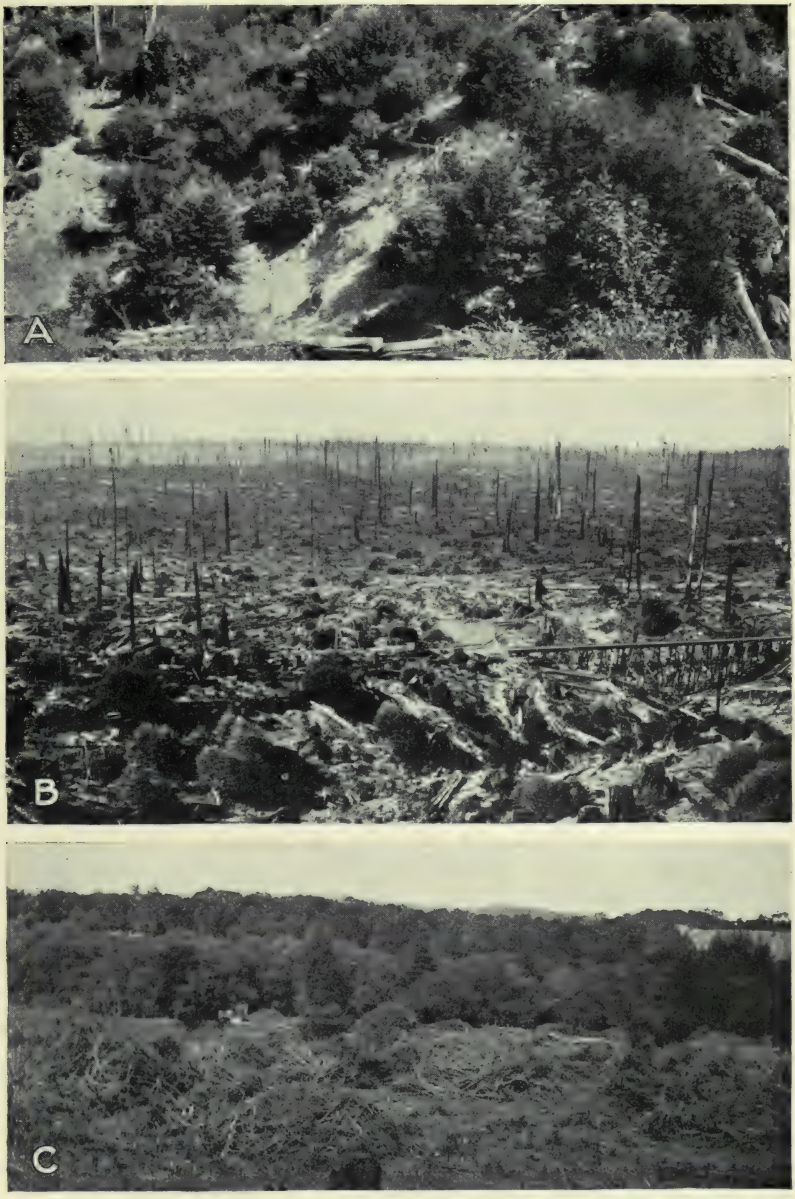
Care with fire on the logging operations is also essential to protect the young forests. Fires started by donkey and railroad engines frequently spread to areas cut in previous years, on which new growth is established.

Measures of demonstrated merit in reducing fires on logging operations include:

The use of oil-burning instead of wood-burning railroad engines: Oil burners sometimes set fires, but very much less frequently than wood burners.

The use of spark arresters with wood-burning engines: Very satisfactory spark arresters are now available at moderate cost and, if consistently used and systematically inspected and kept in order, are an important means of preventing fires.

Care in use of fire in the woods by employees: Fires from this source can be absolutely stopped if a concerted effort is made. Care is particularly needed in smoking, and in lighting fires for warmth.



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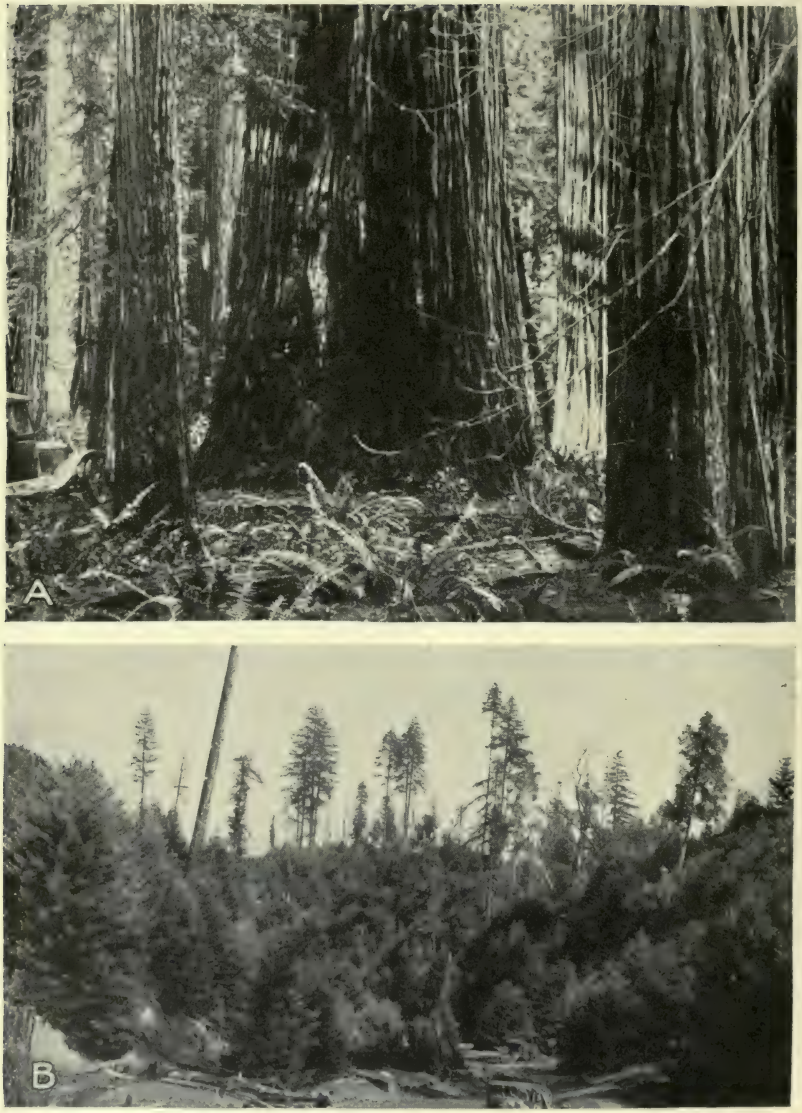
THE IMPORTANCE OF FIRE CONTROL

A, Brush of various species, usually led by the highly inflammable fireweed, soon appears on cutting areas, threatening the new forest with fires that will kill back the redwood sprouts and destroy the seedlings of associated species; B, it is soon evident that where seedlings and seed trees of associated species are destroyed by fire little can be expected of redwood sprouts alone beyond one-fourth or one-third of a desirable stocking of the area; C, such a partially stocked stand is not only low in yield possibilities but high in fire hazard.



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DESIRABLE REDWOOD STANDS, OLD AND NEW

The old giants of the redwood forest (A) are beautiful to behold but unprofitable to grow; they will probably never be equaled in grandeur by the new forest, but fully as profitable stands can be grown where (B) seed trees of Douglas fir and other species have been allowed to survive and have filled in the gaps between the redwood clumps with seedlings; the result is a neat completely stocked stand with brush shaded out, the fire hazard decreased, and a promised yield closely approaching the maximum productivity of the land.

Control of use of lands by campers, hunters, and fishermen: The application of a camp-fire permit system and "no smoking" rules would greatly aid in controlling fires from outside use.

Besides these measures designed to prevent the start of fires, additional special steps can well be taken to handle fires that start. Among the most important are the following:

Placing responsibility for initiating action on fires: On all but the smaller operations a camp firewarden is advisable. He should be commissioned a deputy State firewarden and should be given responsibility for organizing the camps for fire control, teaching the men their duties on fires, enforcing regulations about smoking in the woods, care of spark arresters, time and manner of burning slash, etc. He should be a man of intelligence and energy, and be accustomed to handling men. He should, in short, be specifically charged with fire-control activities on the entire operation and be free from other duties. In addition, some individual at each point of danger should be designated to start action on fires, such as the engineer or fireman at donkey engines, or the hook tender in the woods. The characteristic of logging fires is the long delay in attack due to failure to fix responsibility for starting action. Delay is avoided if a camp-warden system is in effect.

A properly equipped patrol following trains: This method insures prompt detection and suppression of fires starting along rights of way, and is particularly needed for older cutting areas on which the young forest has a good start.

Equipment of donkey engines with pumps, hose, and fire-fighting tools: Where this has been done, serious fires starting from donkey engines have been practically eliminated.

SLASH DISPOSAL

The problem of disposing of the great accumulation of inflammable slash present in the redwood region after falling and bucking is a difficult one. Its solution is perhaps the key step in saving seed trees of associated species and in preventing escape of fires to adjacent young forests. Broadcast burning is generally regarded as the only solution for this problem, but not necessarily haphazard and promiscuous burning.

Care in broadcast burning is essential because of the great loss in seed trees which follows the usual clean-up fire. Many of these trees could be saved by relatively slight and probably inexpensive changes in present slash-firing methods, such as have been made on national-forest cuttings in the Northwest, and with a more than corresponding reduction in cost of timber growing and the avoidance of a good deal of unnecessary planting.

Setting fires at the top instead of the bottom of slopes, clearing slash from around seed trees, burning only at seasons or at times of the day when fires will spread slowly; in short, following the methods and practices employed in most progressive slash disposal in the Douglas fir region, will largely help to solve the problem of preserving seed trees. These simple steps have not, so far as known, been taken systematically in the redwood region.

Despite the immediate reduction of hazard through broadcast burning, the practice probably tends to an actual increase in hazard in the end. Such burning apparently stimulates seed germination of the various brush species, particularly Ceanothus, and thereby creates the dense and highly inflammable stands of brush so characteristic of cut-over and burned-over lands in the region.

A plan well worth trying and with a good chance of success, is the fire-line compartment system recently developed in the Sierra region. Under this method, the area is blocked out into units of 40 to 160 acres by fire lines from 50 to 125 feet wide. On the lines the débris is destroyed, either by broadcast burning or by piling and burning. Elsewhere the slash and débris is left undisturbed. When supplemented by intensive patrol and quick handling of fires this plan has worked very effectively in the pine region. It might well be equally successful in the redwood region.

Besides destroying actual or potential seed trees, the broadcast burning of slash, as now practiced, cleans the ground so thoroughly that serious erosion commonly occurs in the first winter after logging. The presence of erosion is obvious in almost any reasonably careful examination of recent cuttings, but no specific data have been collected on the amount of topsoil lost, or on the more important question, What effect does this loss have on the obtaining of reproduction and the subsequent growth of young trees? The only basis on which a speculative answer to this question may be given is that in other forest regions loss of topsoil, particularly if repeated, has tended to reduce the fertility and productivity of the forest soil.

Detailed studies [7] in parts of the redwood region have led to the conclusion that fire with and after logging has made the second-growth stands open, consisting principally of redwood sprouts, and has caused soil deterioration to a marked degree.

SELECTIVE LOGGING AS A POSSIBILITY

Both past and present practice in the region (with limited exceptions in the early days) involve practically clear-cutting the area and starting the new crop from bare ground. The survival of trees through the logging operation is usually an incident or an accident, rather than something definitely planned.

The plan herein proposed, involving deliberate saving of seed trees of associated species, particularly Douglas fir, does not differ essentially in this regard from the existing method. The new crop will still come from seedlings, sprouts, and planted stock, all starting after logging. The proposal has, however, various apparent advantages over existing practice in obtaining desirable mixtures of species at probably less than the cost of planting. Nevertheless, a full rotation of, say, 50 to 60 years must elapse before the new stand can be cut. (Pl. 4.)

The yields from well-stocked, even-aged second-growth stands are so high that volume production alone has generally been regarded as the goal of forestry in the region. The data [8] on quality of lumber

[7] At the California Forest Experiment Station, under direction of A. E. Wieslander, 1926–1930 (data unpublished).

[8] Unpublished data obtained by E. Fritz, University of California Forest School, has been kindly made available for this discussion. The data are contained in Second Growth Redwood Cutting Experiment, Big River, Mendocino County, Calif., project 688, of July 23, 1923, and Properties and Uses of Second Growth Redwood, project 688.

produced by young even-aged stands as well as by trees reserved in the first cut, and harvested years later, give an approximation of the quality obtainable from the clear cutting and selection systems. Trees on selected plots were followed in detail through the mill, and lumber as sawn out was recorded in the standard lumber grades now in use. The results for second-growth redwood only were as follows, with grades arranged in order from highest to lowest quality:

Grade	Per cent of total	Grade	Per cent of total
Clear	0	No. 2 (construction)	56.8
Sap clear	2.3	No. 3	19.6
Select	.2	No. 1 ties	4.5
Standard	1.6	No. 2 ties	9.3
No. 1 (extra merchantable)	.9	No. 3 ties	4.8

This tabulation shows 4.1 per cent of total number in uppers (the four top grades); 57.7 per cent in No. 1 and No. 2; and 38.2 per cent in the lower and less valuable grades.

On the same area, the lumber produced from a small number of trees left in the original cutting, presumably because they were unmerchantable at that time, was:

Grade	Per cent of total	Grade	Per cent of total
Clear	5.0	No. 2	35.0
Sap clear	19.1	No. 3	25.0
Select	2.0	No. 1 ties	2.1
Standard	4.0	No. 2 ties	2.7
No. 1	4.0	No. 3 ties	1.1

The total of the four top grades is 30.1 per cent; that of the lowest but 30.9 per cent. Average selling price per thousand feet is much higher for the old reserved trees than for the second growth.

Recent studies indicate (*10*) that redwoods 34 inches and less in diameter do not on an average pay their way in logging.

Analyses of stumps of trees left in the older cuttings in the region show unmistakably that redwood possesses to a high degree the capacity for accelerated growth after release by logging. The smaller trees which from an immediate economic standpoint can not be logged and manufactured with profit will, as a group, not only produce wood rapidly if left standing but will also produce the high-quality grades of lumber which are so conspicuously absent from young second-growth trees. It is obviously desirable from the operator's viewpoint to produce in, say, 50 years, the complete range of lumber grades, if for no other reason than that second-growth stands of 1980 will probably still be competing against remnants of virgin stumpage. It seems altogether likely that the selling prices of the present higher grades will remain relatively as much above common lumber in the future.

Taking into account the age composition of the redwood forest, the negative value for immediate exploitation of the smaller diameter trees, the ability of such trees to produce wood rapidly after release, the relatively high percentage of upper lumber grades produced by such reserves as compared with true second growth, and the possibility of an intermediate cut before the second growth shall have attained merchantable size, the results indicate that some form of selection cutting may in the long run well prove to be the most successful and profitable for the operator.

In fact, the attention that is being given in the region to selective logging as a means of increasing net return per thousand feet cut is operating unmistakably in favor of that method of cutting. Unfortunate as the depression has been for the operators, and in causing curtailment of planting, the search for means of weathering the crisis has apparently opened new possibilities for increasing both immediate profits and the long-term return from manufacture, and at the same time for decreasing the cost of reforestation.

MAKING THE CUT CONTINUOUS

In addition to the problems directly involved in obtaining full stands, the operator who is practicing intensive timber growing faces another major problem in adopting a policy of permanent operation. He must adjust his operation so that the supply of virgin timber will last until extensive areas of second growth are large enough for cutting. For example, it may be 35 years before the second growth is ready for logging, while at the present rate of cutting the virgin forest may be gone in 30 years. Under such circumstances, a slight decrease in present cut or an increase in holdings is desirable in order to avoid a shutdown of the operation for several years. The possibility of thinning in second-growth stands is worthy of study as a potential aid in making the cut continuous.

The loss of personnel, maintenance depreciation on mill and railroad, loss of established markets, costs on equipment, and similar items involved in a shutdown, make it obviously necessary to maintain the cut continuously. Protection of the investment is a goal of major importance. The operator should determine how long his virgin stumpage will last at the present rate of cutting and plan to prolong the cutting of virgin timber until the time when the second-growth cut can begin. Such a plan is an integral part of the operation, and is nearly or quite as important as obtaining full stands of timber.

SUMMARY

With the all-important problem of a land policy settled for most of the redwood region, attention can be devoted to the constructive task of growing full crops of timber.

Planting, relatively easy in the redwood region and already under way on a large scale, is one solution. Parallel with the planting program should go an intensive program of research to determine nursery and field-planting technic, the proper spacing to employ, and above all the comparative losses from different methods of putting the young trees into the ground. Natural reproduction is readily obtained in the redwood region. The opportunities for utilizing this method of reforestation have not been thoroughly tested. It appears true that slight modifications in cutting practice, in yarding, and in slash burning can be made to save the seed trees needed to supplement redwood sprouts and to obtain mixed stands of second growth. Research is needed in this field as well. Selective cutting appears as a definite possibility deserving study and experiment.

Regardless of whether planting or natural reforestation or both are used, fire protection on cut-over lands is required. To attain this, the habit of burning, which has been prevalent in the region, must

be modified. Through education and law enforcement, the essential truth must be taught that most redwood cut-over lands are more valuable for timber growing than for grazing or agriculture.

In addition to the economic importance of the notable progress in industrial forestry in the redwood region, the example set is significant. Where the factors of growth, early returns, and rising values are balanced against taxes, compound interest, and fire hazard, and the net return is compared with the probable loss if timber is not grown, sound business judgment is likely to find that the gains from timber growing more than offset the obstacles. Profitable perpetuation of a going concern by deliberate timber growing is chosen rather than the alternative of dismantling the business as soon as the virgin forest is cut.

It is obvious that much more detailed study of this possibility is needed at once. It is equally clear that current logging and slash-disposal practices require modification before selective logging can be adopted. The recent discoveries of economic means for utilizing redwood bark will, as applied, tend in the direction of saving uncut trees from destruction by fire. Surely, it can be expected that the industry, which has already gone so far in intensive-forestry practices, will not overlook the apparent advantages of selective logging.

LITERATURE CITED

(1) BARNES, J. S.
1925. RELATIVE VOLUME PRODUCTION OF REDWOOD SPROUTS AND SEEDLINGS. Timberman 26 (3) : 146, 148.

(2) BRUCE, D.
1923. PRELIMINARY YIELD TABLES FOR SECOND-GROWTH REDWOOD. Calif. Agr. Expt. Sta. Bul. 361, p. [425]–467, illus.

(3) CLARKE, W. T.
1922. AGRICULTURE IN CUT-OVER REDWOOD LANDS. Calif. Agr. Expt. Sta. Bul. 350, p. [167]–186, illus.

(4) FRITZ, E.
1929. SOME POPULAR FALLACIES CONCERNING CALIFORNIA REDWOOD. Madroño 1 : 221–224.

(5) HERZIG, A. S.
1923. FIRE PROTECTION FOR THE REDWOODS. Timberman 24 (11) : 172, 175, illus.

(6) HOFMANN, J. V.
1924. NATURAL REGENERATION OF DOUGLAS FIR IN THE PACIFIC NORTHWEST. U. S. Dept. Agr. Bul. 1200, 63 p., illus.

(7) MCARDLE, R. E., and MEYER, W. H.
1930. THE YIELD OF DOUGLAS FIR IN THE PACIFIC NORTHWEST. U. S. Dept. Agr. Tech. Bul. 201, 64 p., illus.

(8) MASON, D. T.
1922. FOREST MANAGEMENT FOR THE REDWOODS. Timberman 23 (7) : 34, illus.

(9) ———
1923. ATTITUDE OF REDWOOD LUMBERMEN TOWARD REFORESTATION. Commonwealth Club Calif. Trans. 18 (4) : 178–180.

(10) MERRILL, E. D.
1930. FORESTRY. Calif. Agr. Expt. Sta. Ann. Rpt. 1928–29 : 74–79.

(11) METCALF, W.
1924. ARTIFICIAL REPRODUCTION OF REDWOOD (SEQUOIA SEMPERVIRENS). Jour. Forestry 22 : 873–893.

(12) SCHOFIELD, W. R.
1929. REFORESTATION IN THE HUMBOLDT REDWOOD BELT. Jour. Forestry 27 : [168]–175.

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STRENGTH-MOISTURE RELATIONS FOR WOOD

BY

T. R. C. WILSON

Senior Engineer, Forest Products Laboratory
Branch of Research, Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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STRENGTH-MOISTURE RELATIONS FOR WOOD

By T. R. C. WILSON[1]

Senior Engineer, Forest Products Laboratory,[2] Branch of Research, Forest Service

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INTRODUCTION

Wood in the natural state in the living tree has associated with it considerable quantities of water, usually sufficient to make it appear wet. After being converted into lumber or other usable forms or during the conversion it is commonly dried to a state such that wetness is not evident, although appreciable quantities of water remain. During subsequent use it may be soaked or otherwise so exposed as to become obviously wet, or it may be so sheltered that no wetness becomes evident. In the latter case, however, since wood is hygro-

[1] Acknowledgment is made of assistance of various kinds received from J. A. Newlin, H. D. Tiemann, R. P. A. Johnson, T. A. Carlson, R. F. Luxford, L. J. Markwardt, and G. W. Trayer, all of the staff of the Forest Products Laboratory.

[2] Maintained by the U. S. Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin.

scopic, its moisture condition varies with fluctuations in the temperature and the humidity, or dampness, of the air.

When the moisture content is below a certain limit changes in its value are accompanied by changes in many of the properties and characteristics of the wood. Dimensions and numerous strength properties are also affected.

Wood fibers are increased in strength by drying, and a piece of wood in an average air-dry condition may be as much as two and one-half times as strong as a similar piece in the green condition, the ratio varying with the species, with the distribution of moisture, whether uniform or nonuniform, and with the strength property considered. It is obvious then that comparisons among results of strength tests are likely to be greatly in error unless the moisture condition of test material is known in each case and allowance made for any differences that may exist.

The purpose of this bulletin is to discuss the relations between the moisture content and the strength properties of small, clear specimens of wood, to outline the development of formulas that may be used in adjusting strength values for differences in moisture content, and to make clear the applicability and limitations of these formulas. Other phases of moisture-strength relations are also discussed.

The relation of the moisture in wood to its strength properties has been discussed in two preceding publications, neither of which is now available for distribution, namely, Forest Service Bulletin 70 (*12*) [3] and Forest Circular 108 (*13*). This bulletin reviews the principal information presented in these publications and in addition gives the results of subsequent studies and tests.

The changes in strength and other properties of wood with changes in moisture can not be thoroughly understood without some knowledge of how moisture is held in wood, how wood dries, and how it takes on moisture. Also, the method of making moisture determinations is of importance in explaining some of the phenomena.

HOW MOISTURE CONTENT OF WOOD IS DETERMINED AND EXPRESSED

The usual procedure in determining moisture content is to weigh a piece of wood in its original condition and again after heating it at the temperature of boiling water (212° F. or 100° C.) until the weight becomes practically constant. The original weight minus the final weight is taken as the moisture content. This procedure results in error in some instances because substances other than water are evaporated during the heating and some substances other than wood are not evaporated. Methods that are less subject to such errors are available, but the foregoing is the standard method used in determining the moisture content of specimens of wood that have been subjected to mechanical tests and is considered to be sufficiently accurate for the purposes discussed in this bulletin.[4]

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[3] Italic numbers in parentheses refer to Literature Cited, p. 88.

[4] Varying amounts of resin are present in the wood of numerous coniferous species. The heartwood of many species contains infiltrated substances, often strongly colored, in varying amounts. Among native species redwood, various cedars, Osage-orange, and black locust are conspicuous in this respect. The presence of such materials in abnormal amounts appreciably affects the accuracy of the computed percentage moisture content. Such of the extraneous materials as are evaporated in drying the wood are counted as moisture and tend to make the moisture content too high; such as remain after drying are counted as wood and by increasing the weight on which the percentage is based tend to make the moisture content too low. None of the material from which data are presented in this bulletin was abnormal with respect to the amount of resin or other infiltrated substances present.

The relation between the weights obtained may be expressed as follows:

$$Wo - Wf = Wa \quad (1)$$

Where Wo = original weight, Wf = final weight, and Wa = water content or moisture content by weight.

In equation (1) Wa is the moisture content in the same units as the original and final weights. If, for example, weighings were made in pounds, the moisture content could be stated as Wa pounds. Such a statement would, however, have little significance as it would not specify the quantity of wood with which the Wa pounds of water had been associated. Because the piece of wood whose moisture content is determined is usually a sample of a larger piece whose moisture content is sought, and for convenience in expressing certain relationships, the moisture content is commonly stated as a percentage. Either the original or the final weight might be employed as the base of the percentage. Accepted practice in stating the moisture content of wood [5] is to use the final weight as the base of percentages and to express the result as follows:

Per cent moisture content

$$M = 100\frac{Wa}{Wf}, 100\frac{Wo - Wf}{Wf}, \text{or } 100\left(\frac{Wo}{Wf} - 1\right) \quad (2)$$

the three expressions after the sign of equality being identical. This practice is followed throughout this bulletin.

The use of the final weight, that is, the weight of the wood, as the base of the percentage is preferred because it results in percentages whose relationships are very simple. For example, if 120 units by weight of wood has associated with it 60 units of water, the moisture content is 50 per cent, and removal of 30 units, or one-half, of the water reduces the moisture content to 25 per cent, or one-half its former value. The use of the original weight, that is, the weight of the wood and water together, as a base yields percentages whose relationships are much less simple.

MOISTURE CONTENT UNDER VARIOUS CONDITIONS

Water is the principal constituent of the sap of trees. The amount of water or moisture in the wood of living trees varies greatly. In the heartwood of some coniferous species, such as Douglas fir [6] and the southern yellow pines, the moisture content is normally very low (from 25 to 50 per cent) whereas in the sapwood it is much higher (from 100 to 120 per cent or more). In some hardwood species the moisture content is very low both in heartwood and in sapwood. For example, the white ashes average about 40 to 50 per cent moisture content. Some other species, including both conifers and hardwoods, have high moisture content in all parts of the tree.

When a piece of wood is subjected to prolonged soaking in water, it eventually acquires a very high moisture content, at least in the outer portions, which are most accessible to the action of the water. The

[5] In stating the moisture content of wood pulp, the practice of the chemist in defining solutions is followed, and the weight of the combination of wood pulp and water is used as the base of percentages, for example, per cent moisture content of wood pulp equals $100\frac{Wa}{Wo}$.

[6] The standard names employed by the U. S. Forest Service for lumber and for the trees from which it is cut are used throughout this bulletin (*11*).

moisture content in such portions is probably limited only by the space available. That absorption of water by the heartwood of many species is comparatively slow, particularly in pieces that have not been checked in drying, is evident from the observed fact that logs and piling submerged in water for several years are not filled with water throughout.

Figure 1 shows the relation between the equilibrium moisture content of Sitka spruce and the temperature and relative humidity of the air.

For example, if a piece of Sitka spruce is exposed in air maintained at a temperature of 80° F. with relative humidity of 30 per cent it will attain a moisture content of 6 per cent and will remain at this moisture content as long as this temperature and this relative humidity are maintained. Six per cent is then the equilibrium moisture content for Sitka spruce in air at 80° and 30 per cent relative humidity. Figure 1 shows that the equilibrium moisture content value increases with increase in relative humidity and with decrease in temperature of the atmosphere. Experiments have shown that at ordinary temperatures and at relative humidities between 20 and 80 per cent, the different species of wood do not differ much with respect to equilibrium moisture content values.

After a piece of green wood has been subjected to natural atmospheric conditions for some time the moisture content at the surface comes into equilibrium with the current temperature and humidity and thereafter fluctuates with changes in these factors. The equilibrium moisture content varies from as low as 5 to 8 per cent in the more arid, to as high as 18 to 20 per cent or higher in the more humid climates, and at any place varies with changes in weather conditions. The inner portion of the piece continues to dry by transfer of moisture to the surface, where it is evaporated, until finally the center attains a moisture content such that no further drying takes place. How soon such a condition is reached depends on the size of the piece as well as on climatic conditions. If the piece of wood is quite large, such as a 12 by 12 inch by 16-foot timber, several years may be required.

By means of kiln or other artificial drying the moisture content of wood may be reduced to any desired value. Subsequent to such drying the moisture content tends to come into equilibrium with the atmospheric conditions to which the wood is exposed. There is some evidence, however, that the equilibrium moisture content may be lowered slightly by drying the wood to a very low moisture content.

HOW MOISTURE IS ASSOCIATED WITH WOOD

The structure of wood, typical examples of which are illustrated by Figures 2 and 3, allows moisture to exist in two states; as "bound" or "imbibed" moisture, absorbed within the substance of the cell walls, and as "free" water, filling or partially filling the cavities within the cells. Both states obtain in wet or green wood, the free water evidently having no particular effect on the dimensions or on the strength properties but, of course, adding to the weight.

THE FIBER-SATURATION POINT

The theory of the fiber-saturation point was first evolved (*12*) in connection with wood to explain certain phenomena of moisture-

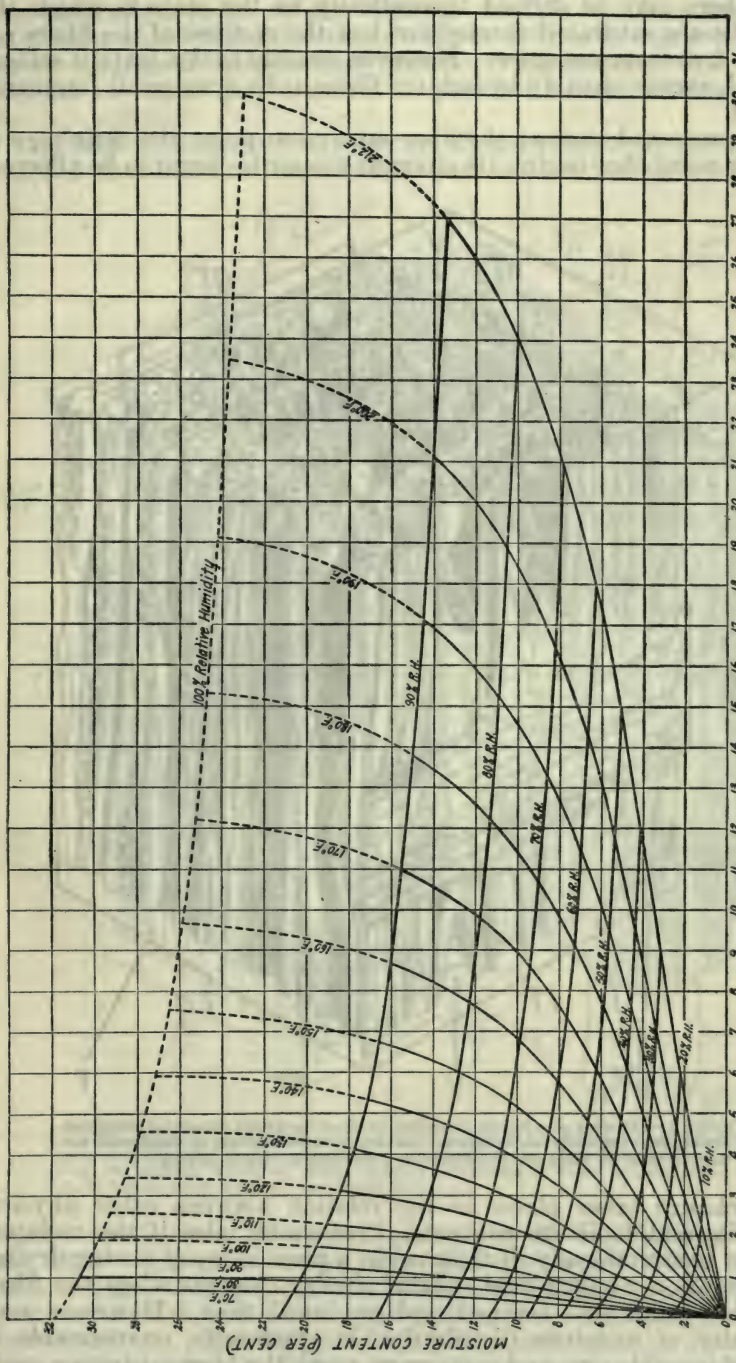

FIGURE 1.—Relation between the equilibrium moisture content of Sitka spruce and indicated values of temperature, relative humidity, and partial vapor pressure. The solid lines in the curves of this figure are based on experimental data; the dotted parts of the lines are calculated

strength and moisture-shrinkage relations. The saturation point of wood fibers may be defined theoretically as the state in which the cell walls are saturated throughout but the cavities of the fibers are entirely free from moisture. However, exactly such a state is seldom attained, except possibly by isolated fibers or by very small fragments of wood.

It is presumed that at the fiber-saturation point the shrinkage of a drying wood fiber begins, its strength properties begin to be affected,

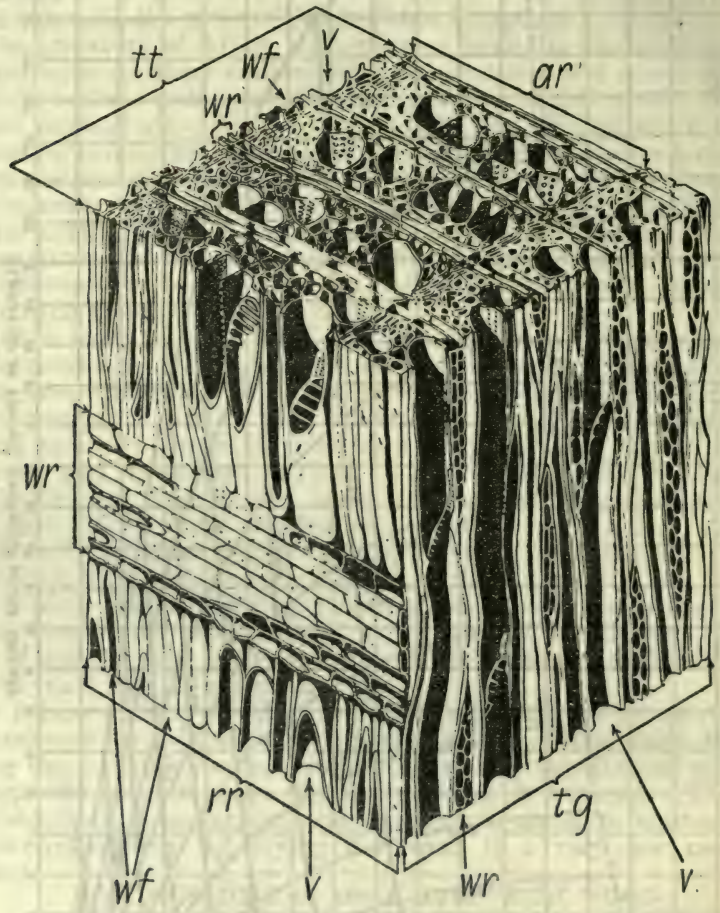

FIGURE 2.—Drawing of a highly magnified block of hardwood measuring about one-fortieth inch vertically: *tt*, Transverse surface; *rr*, radial surface; *tg*, tangential surface; *v*, vessel or pore; *wf*, woodfibers; *wr*, wood rays; *ar*, annual ring

and a change takes places in the relation between other physical properties and moisture content. Presumably also if the moisture could be kept uniformly distributed in a piece of wood during drying, the piece as a whole would exhibit similar changes when the fiber-saturation point was reached and not until then. However, such uniformity of moisture distribution is apparently unattainable in pieces of tangible size, and some parts reach the fiber-saturation point in advance of others. Consequently, changes in properties of a piece

of wood occur before the average moisture content has reached the fiber-saturation point value. Because of this fact the true fiber-saturation point moisture content is not ordinarily marked by any abrupt change in graphs that represent the relation between the strength or other properties of a piece of wood and its average moisture content.

The first systematic study by the Forest Service of the relations between the moisture content of wood and its strength properties

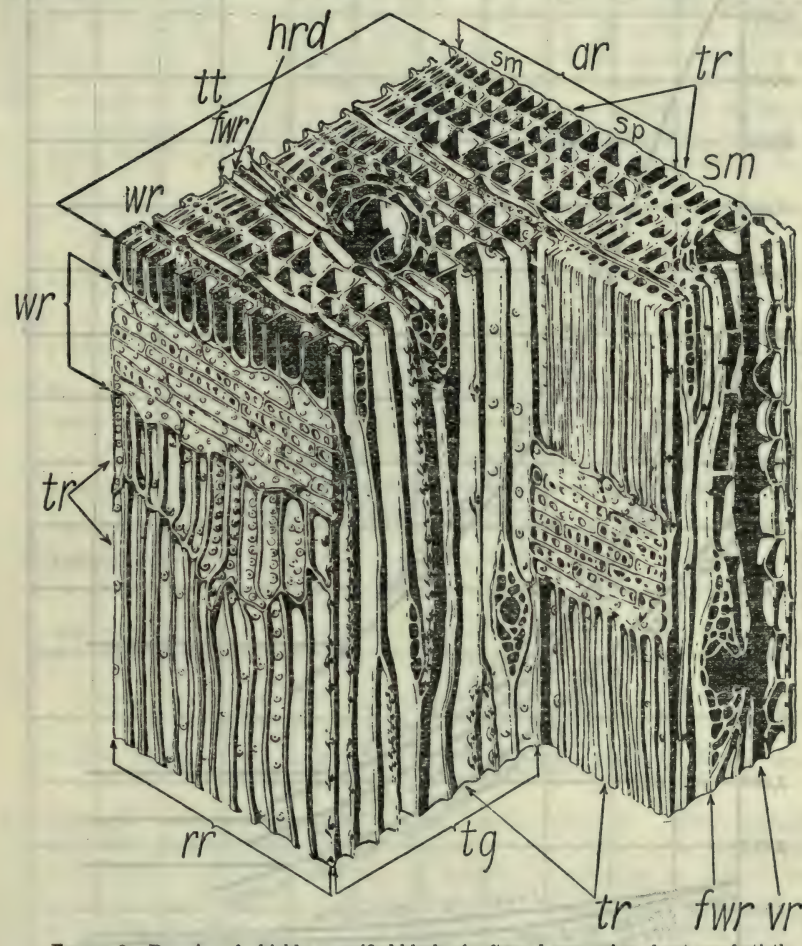

FIGURE 3.—Drawing of a highly magnified block of softwood measuring about one-fortieth inch vertically: *tt*, Transverse surface; *rr*, radial surface; *tg*, tangential surface; *ar*, annual ring; *sm*, summer wood; *sp*, spring wood; *tr*, tracheids, or fibers; *hrd*, horizontal resin duct; *fwr*, fusiform wood ray; *wr*, wood rays

consisted of a series of tests conducted by H. D. Tiemann in 1903 and 1904. European investigators had previously tested wood in various stages of seasoning and had demonstrated the fact of increase in strength with loss of moisture. However, the existence of the fiber-saturation point had not been recognized, and the fiber-saturation-point theory as applied to strength properties and shrinkage was first announced in Forest Service Bulletin 70 (*12*), which presented

the results of the Forest Service tests. Some typical moisture-strength curves as originally derived from these early tests are reproduced in Figure 4.

If the moisture is quite nonuniformly distributed in a piece of wood, the outer shell may be well below the fiber-saturation point while the

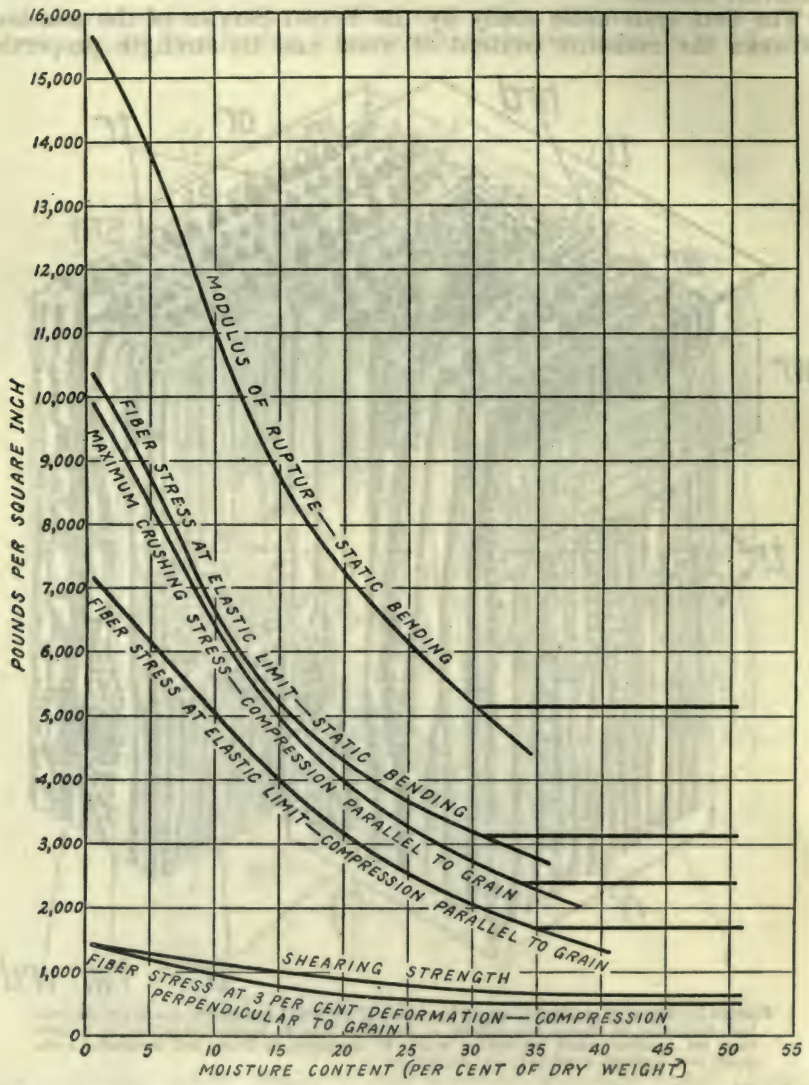

FIGURE 4.—Typical moisture-strength properties curves for red spruce as originally derived from earlier tests

inner part still contains free water. The moisture-strength curve for specimens with moisture nonuniformly distributed may consequently be higher than the correct curve and may be so rounded off from the driest toward the wettest condition as entirely to obscure the fiber-saturation point. Some earlier investigators mistook such curves, an

example of which is shown dotted in Figure 5, as true moisture-strength curves. Recent tests (p. 87) have demonstrated that pieces with nonuniformly distributed moisture content do not always have strength values above the true moisture-strength curve.

MOISTURE-ADJUSTMENT FORMULAS

The early Forest Service tests (*12*, *13*) were concerned with relatively few species of wood and with only a few strength properties. They demonstrated that different strength properties, different species, and, to some extent, different pieces of the same species were affected differently by changes in the moisture content of the wood. The results of these tests were summarized in a series of tables presenting average values of reduction factors, or factors by which the strength value at one moisture content should be multiplied to get

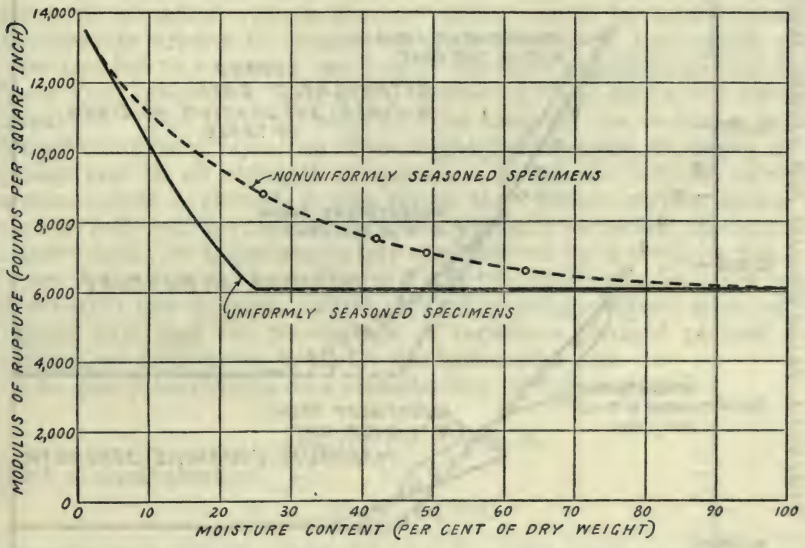

FIGURE 5.—Relation between modulus of rupture and moisture content for chestnut specimens with moisture uniformly and nonuniformly distributed

the strength value at some other moisture content. The reduction factors were taken from curves averaging the relation between moisture content and the respective strength properties as found from tests. The possibility of representing the relation between strength values and moisture content by mathematical formulas was not investigated at that time. Subsequent study of the same and other available data has led to two types of strength-moisture adjustment formulas designated as "straight-line" and "exponential."

STRAIGHT-LINE FORMULAS

The first systematic attempt at representing strength-moisture relations mathematically was the derivation of formulas of a straight-line type. From inspection of such strength-moisture curves as are

shown in Figure 6, it is seen that a comparatively short portion of the curve, such as that between 8 and 12 per cent moisture, does not deviate greatly from a straight-line. In devising a straight-line formula for adjusting to 12 per cent moisture, it was assumed that short portions of a moisture-strength curve to the left and right of 12 per cent moisture could be represented by straight lines whose

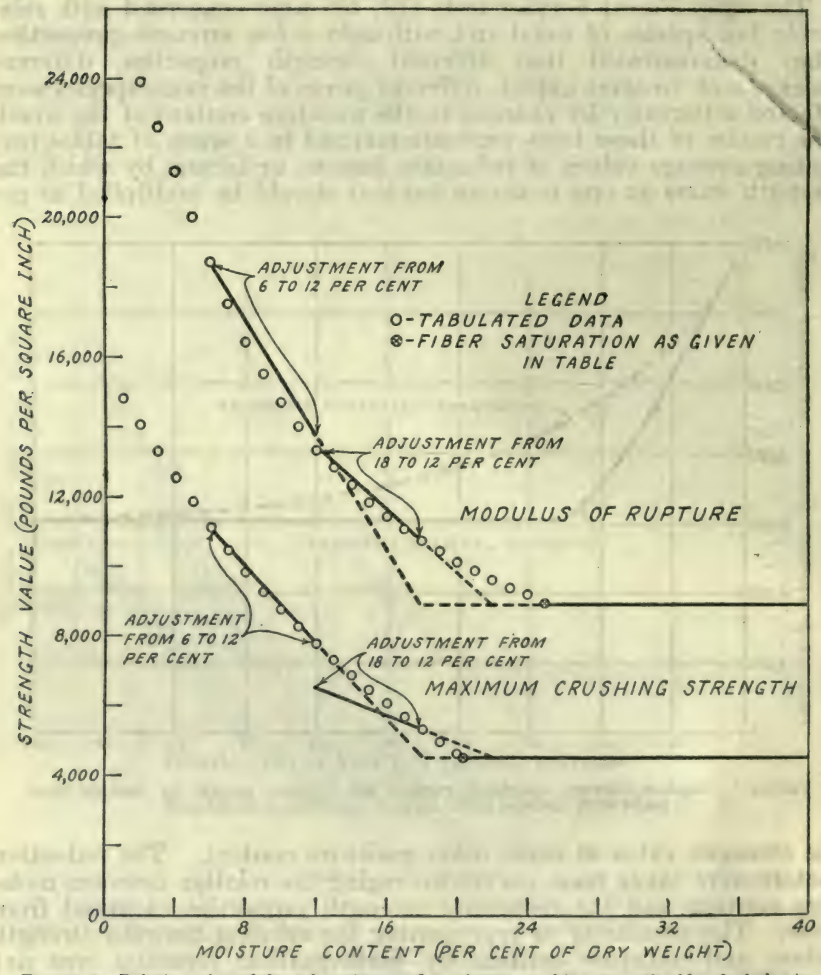

FIGURE 6.—Relation of modulus of rupture and maximum crushing strength of longleaf pine to moisture content and illustration of straight-line formulas. The plotted points are from the curves originally drawn to represent the average strength-moisture relations. Data are from Tables 18 and 19 of Forest Service Bulletin 70 (*12*)

intersections with the horizontal line representing the strength of green wood are at 18 and 22 per cent moisture, respectively. This assumption leads to the following formulas, typical graphs of which are represented by the inclined lines shown in Figure 6:

$$S_{12} = \frac{6(S-G)}{18-M} + G \qquad (3)$$

$$S_{12}=\frac{10(S-G)}{22-M}+G \tag{4}$$

Where S=strength value as obtained from tests at moisture content of M per cent, G=strength value as obtained from tests of matched material in the green condition, and S_{12}=strength value adjusted to 12 per cent moisture content. Formulas (3) and (4) are for use with values of M below and above 12 per cent, respectively.

Similar straight-line formulas for adjusting strength values to 15 per cent moisture were also devised.

EXPONENTIAL FORMULA

It is obvious from Figure 6 that formulas of the straight-line type can be only roughly approximate and that if their applications are not limited to very small moisture differences comparatively large errors in adjusted values are probable. Need for more accurate adjustments arising in connection with a series of tests made some years ago led to a careful analysis of the data available at that time. These data referred to only a few species of wood and a few strength properties. The principal object of the analysis was to find a type of strength-moisture equation that might be assumed to apply to all species and to all strength properties. In all the sets of strength-moisture data reviewed, it was found that within certain limits the relation between the logarithm of the strength value and the moisture content could be quite accurately represented by a straight line. In Figure 7, the curves [7] from Figure 6 and two additional ones are reproduced with the strength values plotted to a logarithmic scale on the vertical axis and the percentage of moisture content plotted to a uniform, or arithmetic, scale on the horizontal axis.

The general equation of a straight line in such a plot is

$$\text{Log } S=\log S_o-KM, \tag{5}$$

which is equivalent to

$$S=S_o\cdot 10^{-KM}. \tag{6}$$

Where S and M are corresponding strength and moisture-content values within the limits of applicability of the equation, S_o is the strength value that will obtain at zero moisture if the equation is valid to that point, and K is an experimentally determined constant, or parameter.

The agreement between the exponential formula and the experimental data is found to be quite good in a large number of instances, and this fact suggests that this type of relation may be a close approximation to the fundamental law of the effect of moisture on strength properties and that the deviations of experimentally obtained values from this law may be largely due to experimental errors. Among the causes of deviation are nonuniform distribution of moisture in test specimens, the disturbing influence of varying amounts of resin or other infiltrated substances in certain species, and particularly the variability of wood and the consequent impossibility of obtaining for

[7] The plotted points in Figures 6 and 7 do not represent actual test results but the curves originally derived from experimental data. As will be shown later, reconsideration of the same data has resulted in different curves to represent the strength-moisture relation.

test at several different moisture-content values specimens that are exactly alike in all particulars except moisture content.

Since moisture content appears in formula (6) as an exponent, the equation is referred to as the exponential strength-moisture formula. Formula (6) is presumed to apply for values of M within part of the range between zero and the intersection of the inclined and horizontal lines in such a diagram as Figure 7. Since as is shown later this intersection does not coincide with the fiber-saturation point as previously

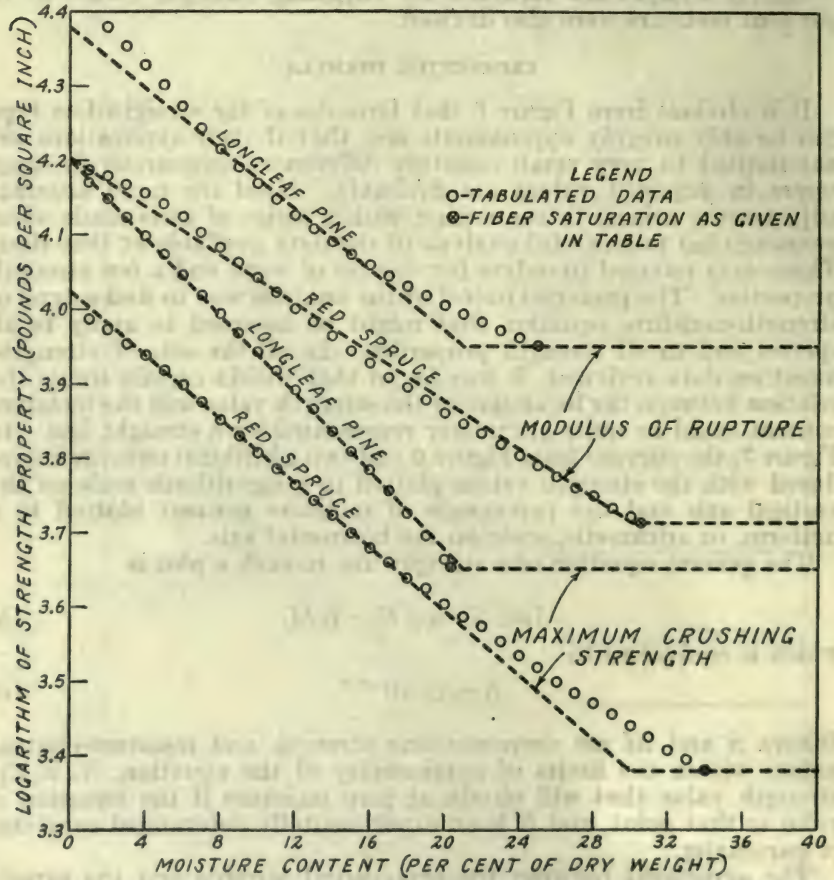

FIGURE 7.—Typical strength-moisture curves plotted semilogarithmically. Data are from Tables 18 and 19 of Forest Service Bulletin 70 (*12*). The plotted points are from the curves originally drawn to represent the average strength-moisture relations. The data for longleaf pine are the same as those shown plotted to an arithmetic scale in Figure 6

defined, a separate name for it is desirable, and it will be called the "intersection point." M_p will then designate the moisture content at the intersection point and S_p the strength value at that point, that is, the strength value for green wood. Then, since S_p and M_p define a point on the inclined line which is represented by equations (5) and (6),

$$S_p = S_o \cdot 10^{-KM_p}, \tag{7}$$

and dividing (6) by (7),

$$\frac{S}{S_p}=10^{K(M_p-M)} \tag{8}$$

or

$$\text{Log } S=\log S_p+K(M_p-M) \tag{9}$$

The form of equations (5) and (9) shows that if the logarithms of experimentally determined values of S, or of the ratio $\frac{S}{S_p}$, are plotted over the corresponding values of M, the conformity of the resulting points to a straight line will measure the agreement of the experimental data with the exponential formula. Also, if a horizontal line representing the strength of green material and an inclined line averaging the points representing material at lower moisture-content values be drawn the intersection of these lines will determine M_p, and the slope of the inclined line will represent K. The value of K is numerically equal to the slope but of opposite algebraic sign. Thus K is positive and the slope negative for properties that increase with decrease of moisture content.

DATA FROM TESTS OF WOOD AT VARIOUS MOISTURE-CONTENT VALUES

The several series of tests that afford data for study of strength-moisture relations are divided for description and discussion into two groups: (1) The early Forest Service tests previously mentioned (*12*, *13*); (2) tests made more recently at the Forest Products Laboratory on Sitka spruce, Douglas fir, white ash, and yellow birch. The tests of Group 2 were made with the specific object of studying the exponential type of equation as a means of representing strength-moisture relations. Species and properties not previously studied were included.

The data from tests of both groups are presented in diagrams in each of which the strength values to a logarithmic scale are plotted above the corresponding moisture-content values to an arithmetic scale; the strength value for green or soaked control specimens is represented by a horizontal line. In plotting, a different zero of the logarithmic scale is used for each series of points.

GROUP 1. EARLY FOREST SERVICE TESTS

The following quotations from Forest Service Circular 108 (*13*, *p. 6–7*, *10–11*) give pertinent information concerning Group 1 tests:

> The selection of test specimens and their proper treatment to secure the desired conditions constituted the chief part of the problem, and required much more time and attention than the tests themselves.
>
> The specimens were carefully cut and placed in series, so that each series consisted of a number of specimens, cut either from the same strip of wood or from adjacent strips in the log or plank, having practically the same straight grain, and free from defects. Each specimen in a series was brought to a different moisture degree in such a manner that the moisture was uniformly distributed. From 7 to 16 of such series of specimens were made for each species of wood and each kind of test.
>
> Tests were made in bending, compression parallel to grain, shearing parallel to grain, and compression at right angles to grain. The sizes of the specimens used were 2 by 2 by 40 inches for bending with a span of 36 inches; 2 by 2 by 5¾

and 2 by 2 by 12 inches for compression parallel to grain and at right angles to grain, respectively; and 2 by 2 by 3 inches for shearing tests in the case of longleaf pine, red spruce, and chestnut. Smaller sizes were used in the subsequent tests upon loblolly pine, red gum, Douglas fir, Norway pine, and tamarack.

The results of the tests were plotted on cross-section paper, and graphically averaged by drawing a separate curve for each series. These series curves were then averaged for the average curve of the species.

The compression tests parallel to grain gave the most uniform and reliable results, and therefore formed the chief subject of the study. Bending tests were made upon the first three species, and also enough upon the next three to establish the fact that the law derived from compression tests applies also to beams. * * *

The moisture was determined by cutting a cross-sectional disk at the point of failure an inch or less in thickness (length) and drying this to constant weight at the boiling point of water. The weight of moisture lost in drying is expressed as a per cent of this dry weight and represents the "moisture per cent" at which the test was made. Other disks were also taken to determine the distribution of moisture. Experiments were made to determine the amount of moisture still remaining in the disk after drying in the manner just described by further drying in vacuum, the average result of which showed that about 0.7 per cent of moisture remained when the disks were dried by the ordinary method. The amount of volatile oils and other matter which escaped in drying the disks was found to be negligible.

* * * * * * *

The best way to determine the fiber-saturation point is by actual tests of the strength of very small specimens. Compression tests similar to the moisture-strength tests were made for this purpose upon series of very small specimens—from 1 to 1½ inches long and from half an inch to 1 square inch in cross section. It is better to use such small pieces for these tests because they may be brought more accurately to the desired moisture condition, and with more uniform distribution of moisture, and also because greater uniformity may thus be obtained in the structure of the specimens of each series.

As shown by the preceding quotations, Group 1 included special tests of small specimens for the determination of the fiber-saturation point and tests of larger specimens for finding the average effect of moisture on strength. Fiber-saturation points also were determined from the latter tests.

Data from tests of 2 by 2 inch specimens are shown in Figures 8 to 11 and Tables 1 to 4 and those from the special compression tests on smaller specimens in Figures 12 and 13 and Tables 5 and 6.

TABLE 1.—*Data pertaining to Figure 8*

Kind of test	Number of specimens tested at each moisture content	Property	Average value [1] for control specimens	Value of K
Static bending	5	Modulus of elasticity	1,896,000	0.0062
		Modulus of rupture	8,890	.0210
		Fiber stress at elastic limit	4,920	.0245
		Work to elastic limit	0.73	.0396
Compression parallel to grain	6	Modulus of elasticity	1,227,000	.0109
		Fiber stress at elastic limit	3,515	.0228
		Maximum crushing strength	4,605	.0257
		Work to elastic limit	5.16	.0348
Shear	7	Average of radial and tangential shearing stress.	915	.0157

[1] Units of inch-pounds per cubic inch for work to elastic limit; pounds per square inch for others.

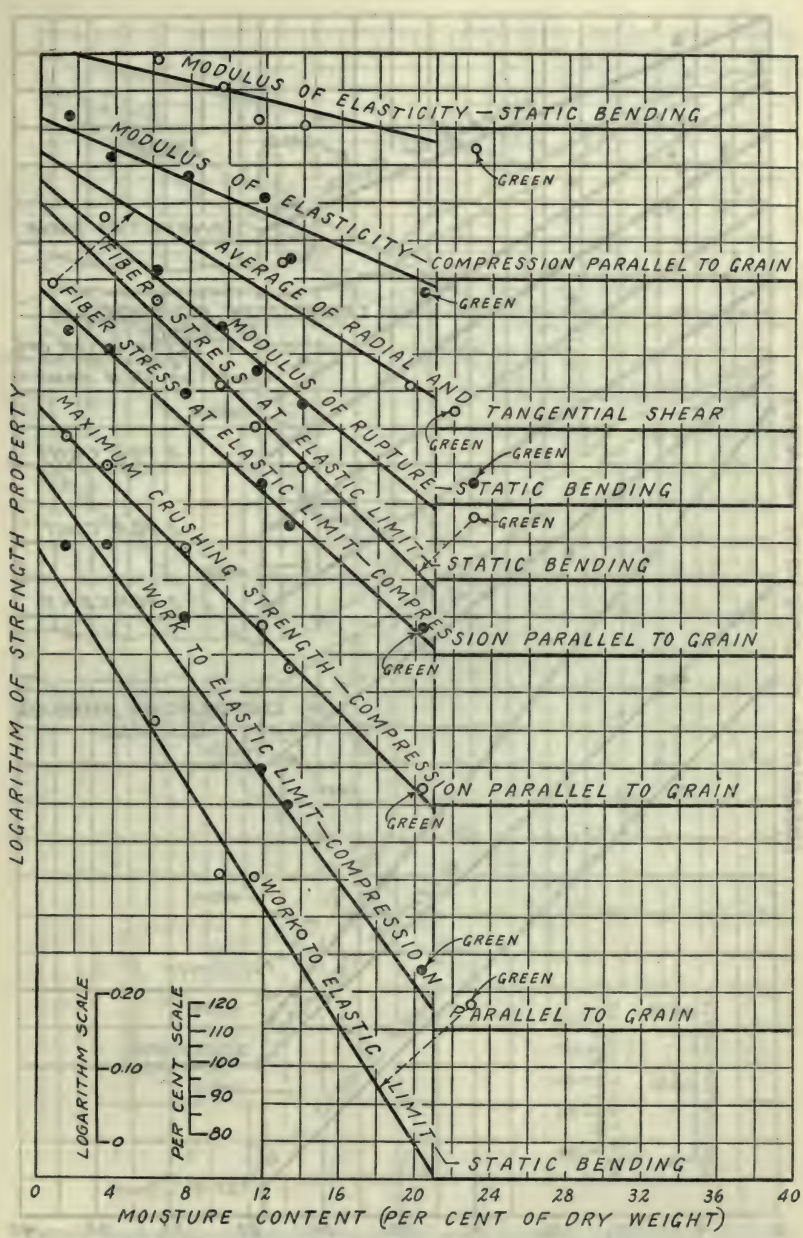

FIGURE 8.—Strength-moisture relations for longleaf pine, specimens 2 by 2 inches. Data are from Tables 1, 5, and 10 of Forest Service Bulletin 70 (*12*). Control specimens, which are represented by horizontal lines, were soaked to insure a moisture content above the fiber-saturation point. Points labeled "green" represent specimens tested as soon as received. For detailed data see Table 1

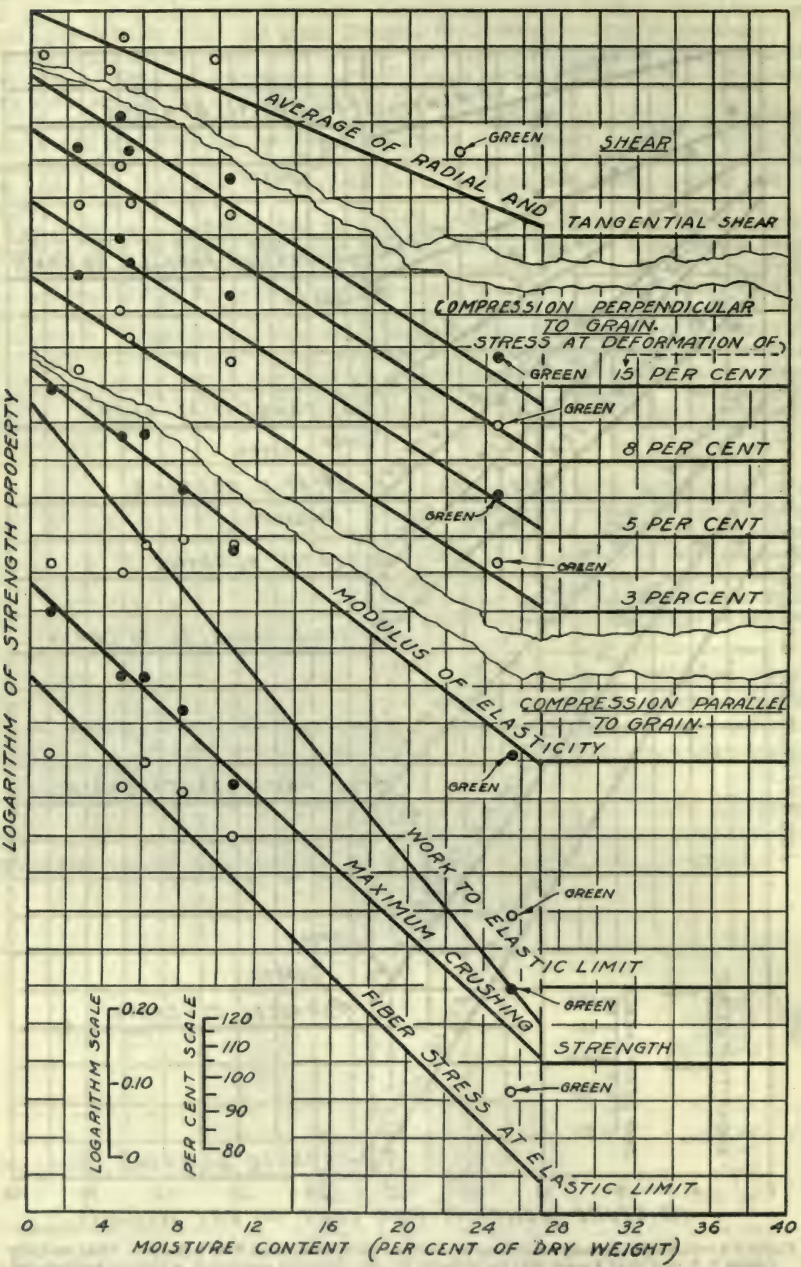

FIGURE 9.—Strength-moisture relations for red spruce, specimens 2 by 2 inches. Data are from Tables 3, 8, and 12 of Forest Service Bulletin 70 (*12*). Control specimens, which are represented by horizontal lines, were soaked to insure a moisture content above the fiber-saturation point. Points labeled "green" represent specimens kept in damp box outdoors from October to February. For detailed data see Table 2

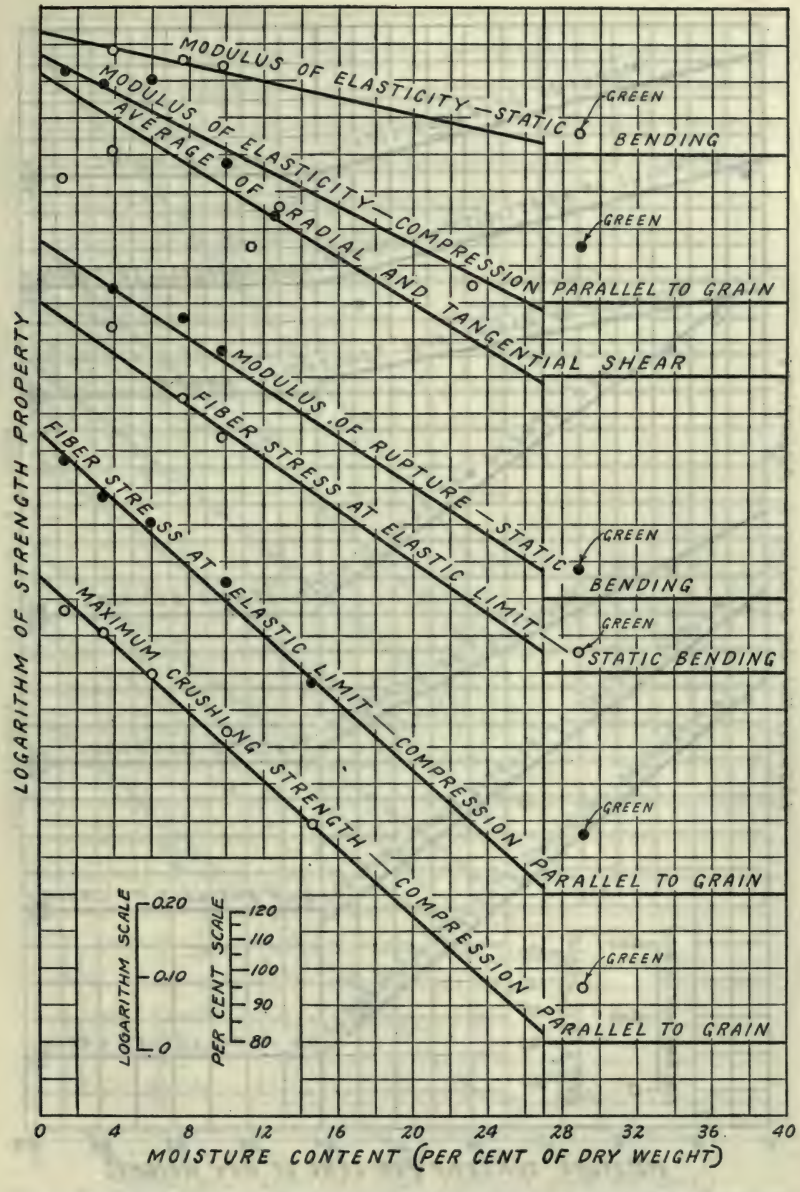

FIGURE 10.—Strength-moisture relations for red spruce, specimens 2 by 2 inches. Data are from Tables 2, 6, and 9 of Forest Service Bulletin 70 (*12*). Control specimens, which are represented by horizontal lines, were soaked to insure a moisture content above the fiber-saturation point. Points labeled "green" represent specimens stored in damp box from 2 to 14 days before testing. For detailed data see Table 3

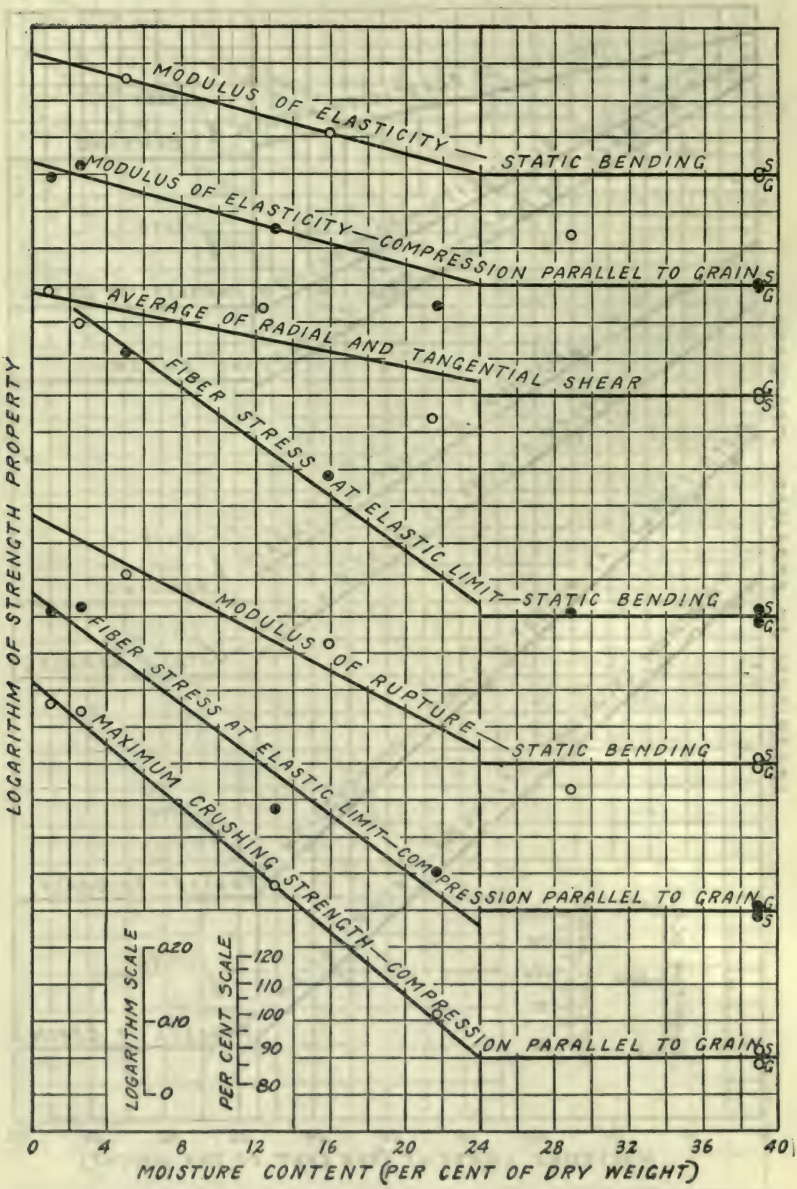

FIGURE 11.—Strength-moisture relations for chestnut, specimens 2 by 2 inches. Data are from Tables 4, 7, and 11 of Forest Service Bulletin 70 (*12*). Points marked *S* and *G* represent soaked and green specimens, respectively. Moisture content values were as follows: Soaked minimum 113, average 135 per cent; green minimum 100, average 123 per cent. Control values, which are represented by horizontal lines, are the average between soaked and green specimens. For detailed data see Table 4

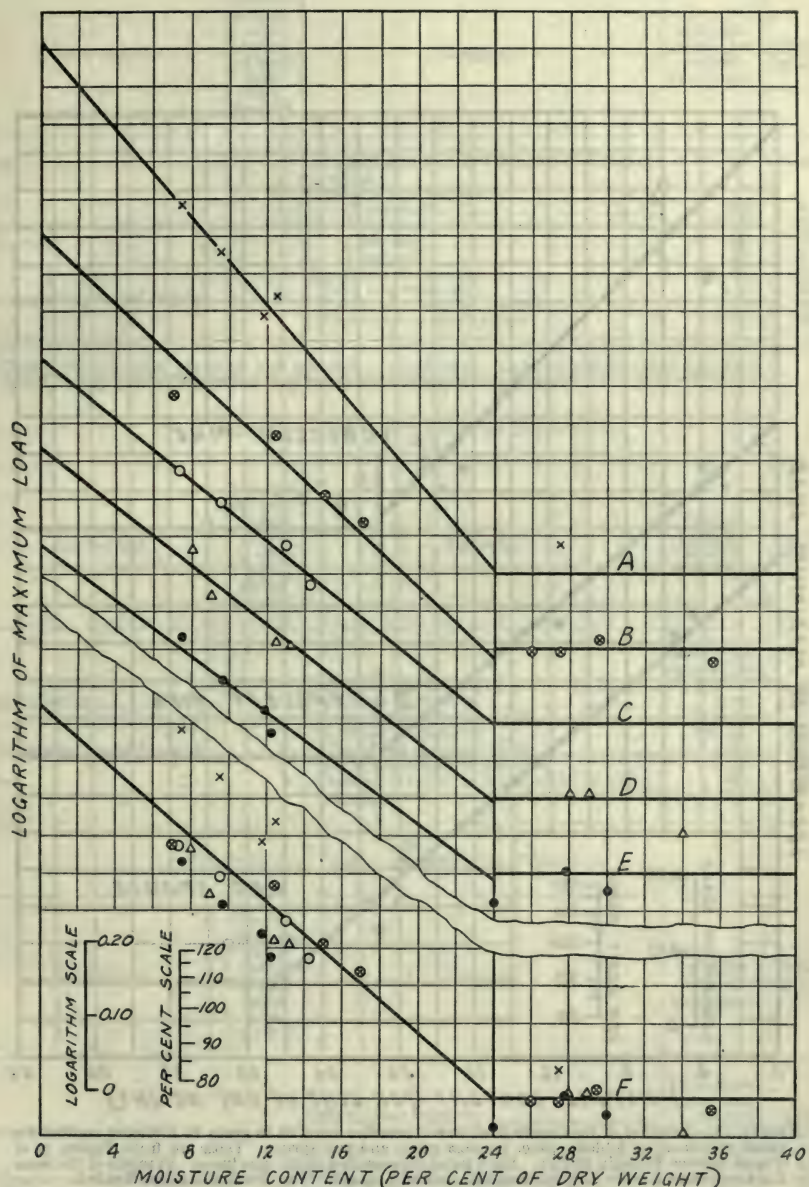

FIGURE 12.—Relation of the maximum load in compression parallel to grain to moisture content for chestnut, specimens $1\frac{3}{16}$ by $1\frac{3}{16}$ by $1\frac{1}{2}$ inches. Data are from Figure 18 of Forest Service Bulletin 70 (*12*). Each plotted point represents a single test. Symbols of the same kind represent a series of specimens matched end-to-end. At *F* all individual values are replotted with reference to the same zero. For detailed data see Table 5

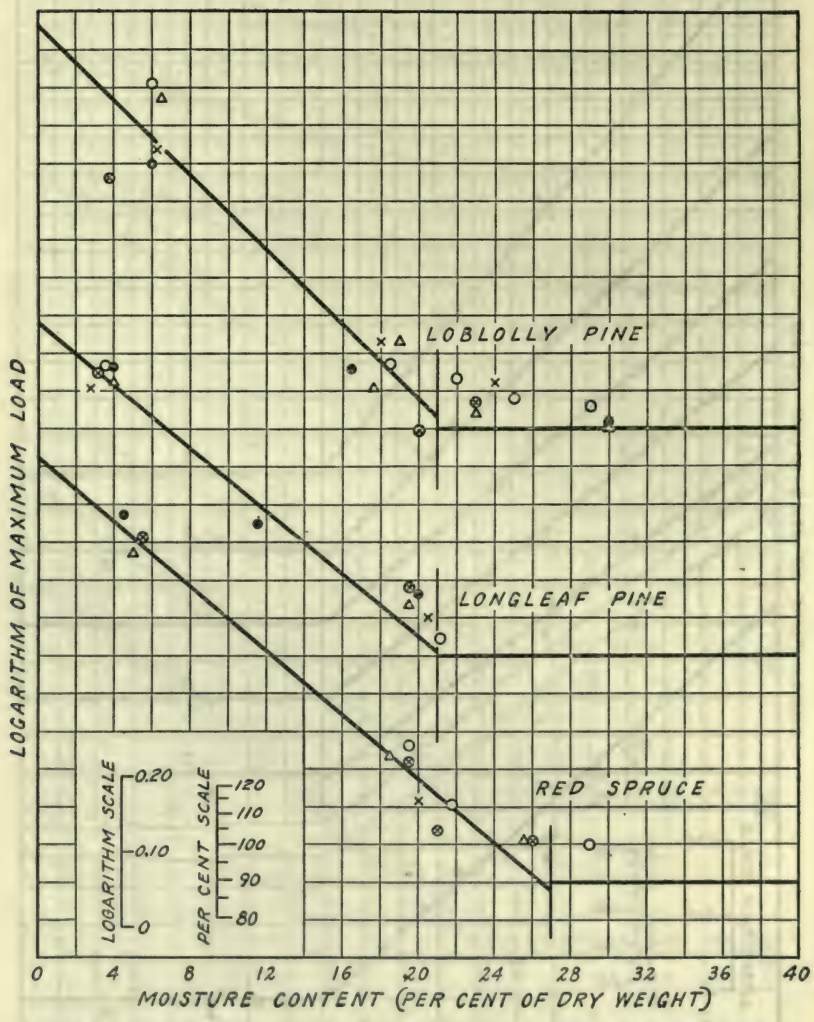

FIGURE 13.—Relation of maximum load in compression parallel to grain to moisture content for small specimens of loblolly pine, longleaf pine, and red spruce. Data are from Figure 18 of Forest Service Bulletin 70 (*12*). Each point represents a single specimen. Symbols of the same kind represent a series of specimens matched end-to-end. For detailed data see Table 6

TABLE 2.—*Data pertaining to Figure 9*

Kind of test	Number of specimens tested at each moisture content	Property	Average value [1] for control specimens	Value of K
Shear	8	Average of radial and tangential shearing stress.	677	0.0105
Compression perpendicular [2] to grain.	5	Stress at deformation of:		
		15 per cent	688	.0163
		8 per cent	587	.0163
		5 per cent	531	.0163
		3 per cent	481	.0163
Compression parallel to grain	5	Modulus of elasticity	476,000	.0193
		Work to elastic limit	4.30	.0306
		Maximum crushing strength	2,620	.0234
		Fiber stress at elastic limit	1,670	.0250

[1] Units of inch-pounds per cubic inch for work to elastic limit; pounds per square inch for others.
[2] Specimens 12 inches long loaded over the center 4 inches of the length.

TABLE 3.—*Data pertaining to Figure 10*

Kind of test	Number of specimens tested at each moisture content	Property	Average value for control specimens	Value of K
			Pounds per square inch	
Static bending	12	Modulus of elasticity	1,262,000	0.0056
		Modulus of rupture	5,165	.0166
		Fiber stress at elastic limit	3,160	.0176
Compression parallel to grain	11	Modulus of elasticity	651,000	.0129
		Fiber stress at elastic limit	1,765	.0227
		Maximum crushing strength	2,410	.0229
Shear	8	Average of radial and tangential shearing stress.	608	.0155

TABLE 4.—*Data pertaining to Figure 11*

Kind of test	Number of specimens tested at each moisture content	Property	Average value for control specimens	Value of K
			Pounds per square inch	
Static bending	10	Modulus of elasticity	1,068,000	0.0068
		Fiber stress at elastic limit	3,570	.0187
		Modulus of rupture	6,270	.0132
Compression parallel to grain	10	Modulus of elasticity	790,000	.0069
		Fiber stress at elastic limit	2,475	.0179
		Maximum crushing strength	3,070	.0214
Shear	10	Average of radial and tangential shearing stress.	733	.0052

TABLE 5.—*Data pertaining to Figure 12*

Reference letter	Maximum load for green specimen	Value of K	Reference letter	Maximum load for green specimen	Value of K
	Pounds			*Pounds*	
A	1,600	0.0294	D	2,070	.0197
B	1,560	.0236	E	2,960	.0185
C	2,650	.0203	F		.0218

TABLE 6.—*Data pertaining to Figure 13*

Species	Size of specimens	Average maximum load for green specimens	Value of K
		Pounds	
Loblolly pine	1 by 1 by 1½ inches	2,010	0.0247
Longleaf pine	¾ by ¾ by 1½ inches	3,220	.0207
Red spruce	do	1,450	.0217

Points labeled "green" in these figures represent specimens tested at approximately the moisture content they had when first prepared. In numerous instances there was doubt as to whether the moisture content was above the fiber-saturation point in all parts of such specimens, and additional specimens were soaked to insure moisture-content values above this point.

The significance of various features of these graphs and tables is more fully described in connection with the later discussion of the data. (P. 41.)

GROUP 2. TESTS MADE AT THE FOREST PRODUCTS LABORATORY

MATERIAL

All specimens for Group 2 tests were obtained from logs cut for the purpose. Information concerning these logs follows.

Sitka spruce from near Gray's Harbor, Wash.—Two 6-foot logs from each of four trees and three 6-foot logs from a fifth tree were selected. The logs were taken from various positions in the tree, the height varying from 18 to 80 feet. Top diameters were from 22 to 41 inches. The number of annual rings showing on the end of a log was from 245 to 340.

Douglas fir from near Gray's Harbor, Wash.—Two 6-foot logs from each of five trees were selected. One log from each was taken about 30 feet and the other about 75 feet above the stump. Top diameters varied from 29 to 47 inches. The number of annual rings showing on the end of a log was from 475 to 700.

Yellow birch from near Neopit, Wis.—One 12-foot and eight 16-foot logs were cut from seven different trees. Two were butt and the others second logs. Top diameters varied from 15 to 24 inches. The ages of the trees ranged from about 200 to about 260 years.

White ash from near Richland Center, Wis.—One 20-foot, one 12-foot, and two 8-foot butt logs and one 4-foot bolt, the butt of which was 4 feet above the stump, were selected. Trees from which the logs were cut were 125 to 145 years old and from 18 to 24 inches in diameter breast high.

MATCHING OF TEST SPECIMENS

In tests to determine the effect of any one variable, such as moisture, it is obviously desirable that the specimens of a series be carefully matched; that is, that they differ as little as possible with respect to variables other than the single one whose effect is to be determined. In the tests of Group 1 this result was sought through individual matching of specimens, and each series consisted of specimens obtained as nearly as possible from contiguous positions within the same group of annual growth layers.

In preparing the material for the Group 2 tests, each white ash and yellow birch log was cut into 4-foot bolts. These bolts and the 6-foot logs of Douglas fir and Sitka spruce were then sawed into sticks of the proper size from which to prepare test specimens.

Sticks from each bolt or log were assigned to each of eight sets. One of these sets was used for tests in the green condition, and the others were used for tests after drying to approximately 25, 20, 15, 12, 10, 8, 5, and 3 per cent moisture content.

The method of cutting and distributing specimens was such as to make the average quality of the material in the several moisture-content sets approximately the same and hence afforded excellent group matching among the several sets as a whole and reasonably good matching among the subsets derived from any one tree. In other words, a fairly large number of specimens rather than individual matching (as in the Group 1 tests) was depended upon to provide data in which the influence of factors other than the differences in moisture content would be averaged out.

Material from several trees of each species and from different heights in the trees was provided in order to cover some of the variations in the strength properties of wood and some of the expected variations in strength-moisture relations. However, all trees of a species were from the same source.

DRYING AND TESTING

In the Group 2 tests all specimens of a species, except those for test in the green condition, were dried together in a kiln at temperatures that previous experience had indicated would have no injurious effect on the strength properties. The entire charge was first dried to approximately 25 per cent moisture content and so conditioned that in so far as possible the moisture was uniformly distributed in each piece and the stock free from drying or shrinkage stresses. Kiln conditions were then regulated to prevent further change of moisture content and the specimens of one set withdrawn a few at a time, machined to the desired standard size and form, and returned to the kiln where they remained until needed for test when they were again removed from the kiln a few at a time, placed in air-tight containers and cooled to normal temperature, and the tests made. When the testing of one set of specimens had been completed the remainder of the charge was similarly dried and conditioned to the next lower moisture content, when another set of specimens was withdrawn and tested. This was repeated until the last set had been tested. Check determinations showed that no significant change in moisture content or its distribution occurred during the short period required for the final removal from the kiln and the testing.

All specimens were 2 by 2 inches in cross section and tests were made in accordance with standard Forest Service methods (*2*).

Data from the Group 2 tests are shown in Figures 14 to 25 and Tables 7 to 16. These figures and tables are more fully described in the discussion of the data. (P. 38.)

TABLE 7.—*Data pertaining to Figure 14*

Kind of test	Property	Average value [1] for green specimens	*K*
Impact bending	Maximum drop	24	0.0027
	Fiber stress at elastic limit	7,870	.0090
	Modulus of elasticity	1,365,000	.0079
	Work to elastic limit	2.61	.0101
Static bending	Modulus of elasticity	1,371,000	.0060
	Work to maximum load	5.93	.0099
	Modulus of rupture	6,200	.0147
	Fiber stress at elastic limit	3,755	.0161
	Work to elastic limit	0.61	.0260
Shear	Average of radial and tangential shearing stress.	730	.0072
Compression parallel to grain	Maximum crushing strength	3,070	.0200
Compression perpendicular to grain	Fiber stress at elastic limit	335	.0187

[1] Inches for maximum drop; inch-pounds per cubic inch for work values; pounds per square inch for others.

TABLE 8.—*Detailed data pertaining to Figure 15*

Tree	Reference letter	Specific gravity [1]	Average value	*K*
			Lbs. per sq. in.	
No. 6	A	0.476	3,735	0.0184
No. 1	B	.439	2,835	.0213
No. 3	C	.461	3,230	.0199
No. 4	D	.405	2,845	.0196
No. 5	E	.416	2,870	.0212
Average	F	.439	3,070	.0200

[1] Average value for all specimens tested. Based on weight and volume when oven dry. The average specific gravity based on weight when oven dry and volume when green was 0.375 for all specimens tested in the green condition.

TABLE 9.—*Data pertaining to Figure 17*

Group	Average values for green specimens		*K*
	Specific gravity [1]	Maximum crushing strength	
		Lbs. per sq. in.	
A	0.414	3,540	0.0199
B	.385	3,160	.0206
C	.359	2,850	.0200
D	.335	2,710	.0186

[1] Based on volume when green and weight when oven dry.

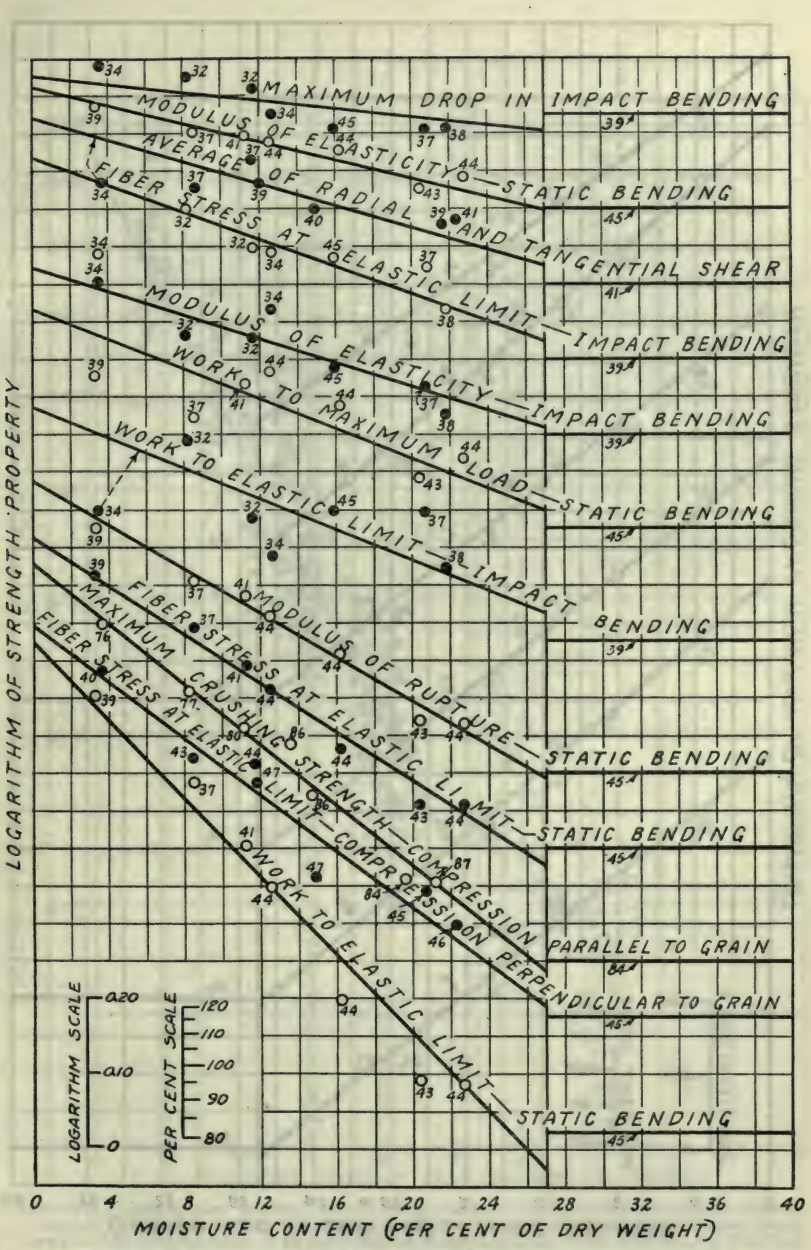
MAXIMUM DROP IN IMPACT BENDING
MODULUS OF ELASTICITY—STATIC BENDING
AVERAGE OF RADIAL AND TANGENTIAL SHEAR
FIBER STRESS AT ELASTIC LIMIT—IMPACT BENDING
MODULUS OF ELASTICITY—IMPACT BENDING
WORK TO MAXIMUM LOAD—STATIC BENDING
WORK TO ELASTIC LIMIT—IMPACT BENDING
MODULUS OF RUPTURE—STATIC BENDING
FIBER STRESS AT ELASTIC LIMIT—STATIC BENDING
MAXIMUM CRUSHING STRENGTH—COMPRESSION PARALLEL TO GRAIN
FIBER STRESS AT ELASTIC LIMIT—COMPRESSION PERPENDICULAR TO GRAIN
WORK TO ELASTIC LIMIT—STATIC BENDING
LOGARITHM SCALE
PER CENT SCALE
LOGARITHM OF STRENGTH PROPERTY
MOISTURE CONTENT (PER CENT OF DRY WEIGHT)

FIGURE 14.—Sitka spruce: Relation of average values of various strength properties to moisture content. Numerals at plotted points and on horizontal lines are numbers of tests averaged. For detailed data see Table 7

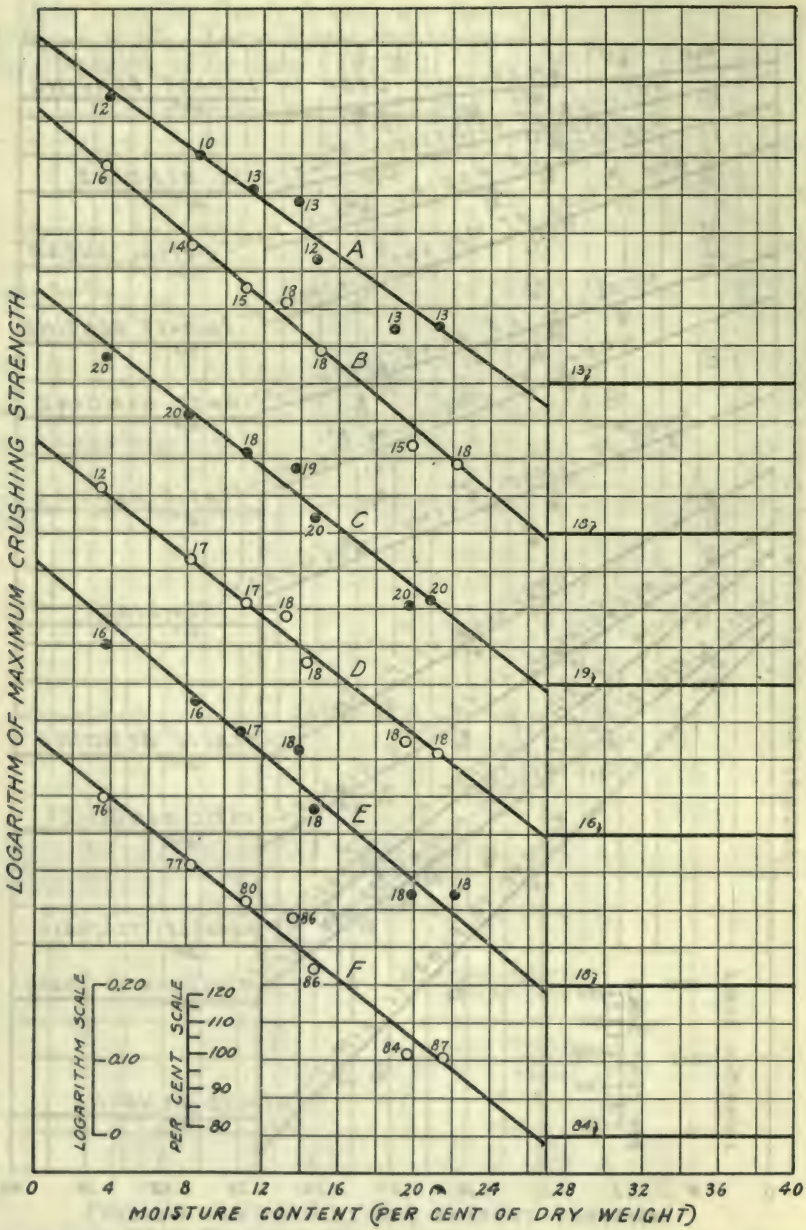

FIGURE 15.—Sitka spruce: Relation, by individual trees, of maximum crushing strength in compression parallel to grain to moisture content. Numerals at plotted points and on horizontal lines are numbers of tests averaged. Letters *A* to *E* each designate data for specimens from one tree. *F* is data for all trees combined and is identical with the maximum crushing strength graph shown in Figure 14. For detailed data see Table 8

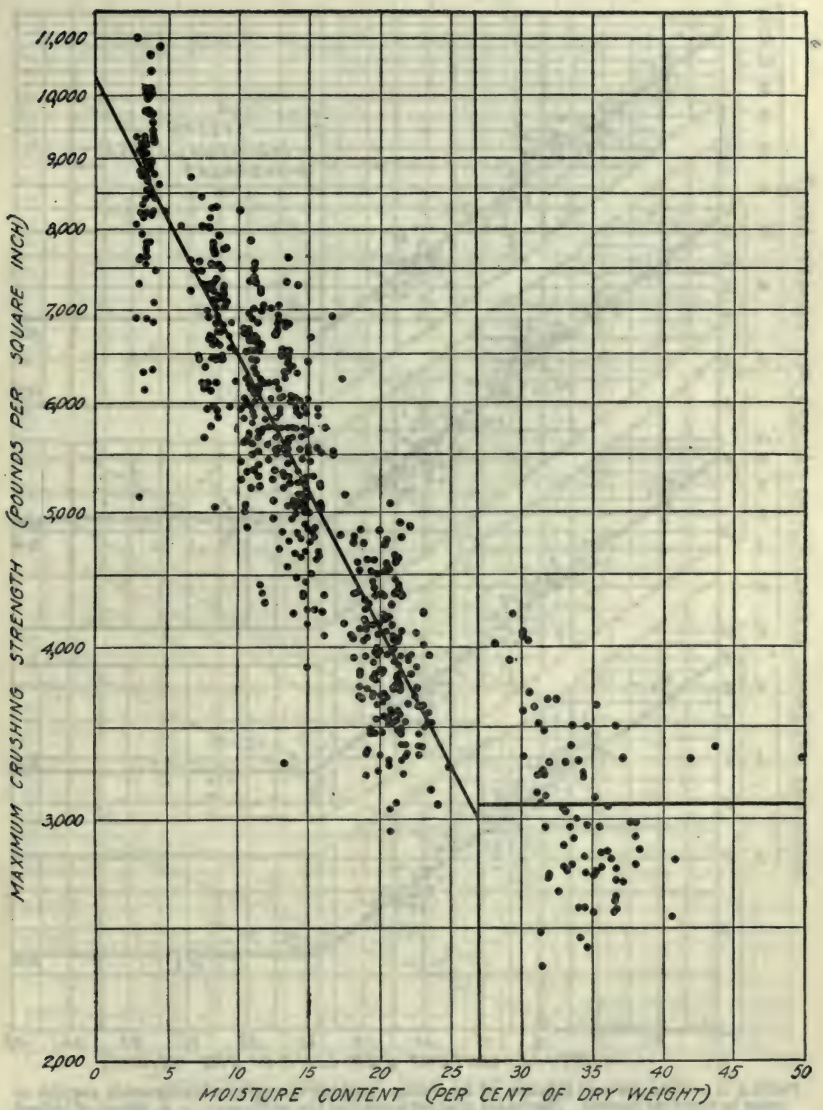

FIGURE 16.—Sitka spruce: Relation, by individual specimens, of maximum crushing strength in compression parallel to grain to moisture content. The inclined and horizontal lines shown are identical with those shown for maximum crushing strength in Figure 14 and at *F* in Figure 15

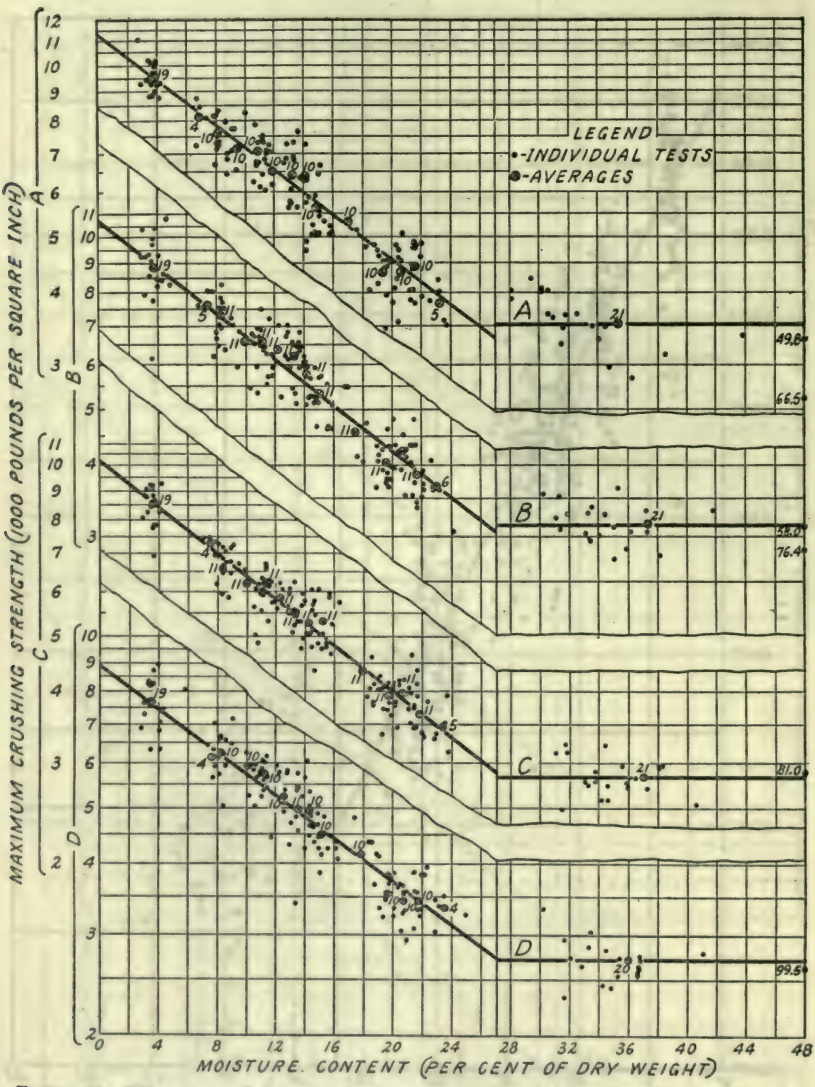

FIGURE 17.—Sitka spruce: Relation of maximum crushing strength in compression parallel to grain to moisture content. Specimens grouped according to specific gravity: *A*, Group of highest specific gravity; *B*, group of next lower specific gravity; *C*, group of next lower specific gravity; *D*, group of lowest specific gravity. Figures near right-hand border are moisture-content values that are not plotted to scale. Numerals at other plotted points and on horizontal lines are numbers of specimens averaged. For detailed data see Table 9

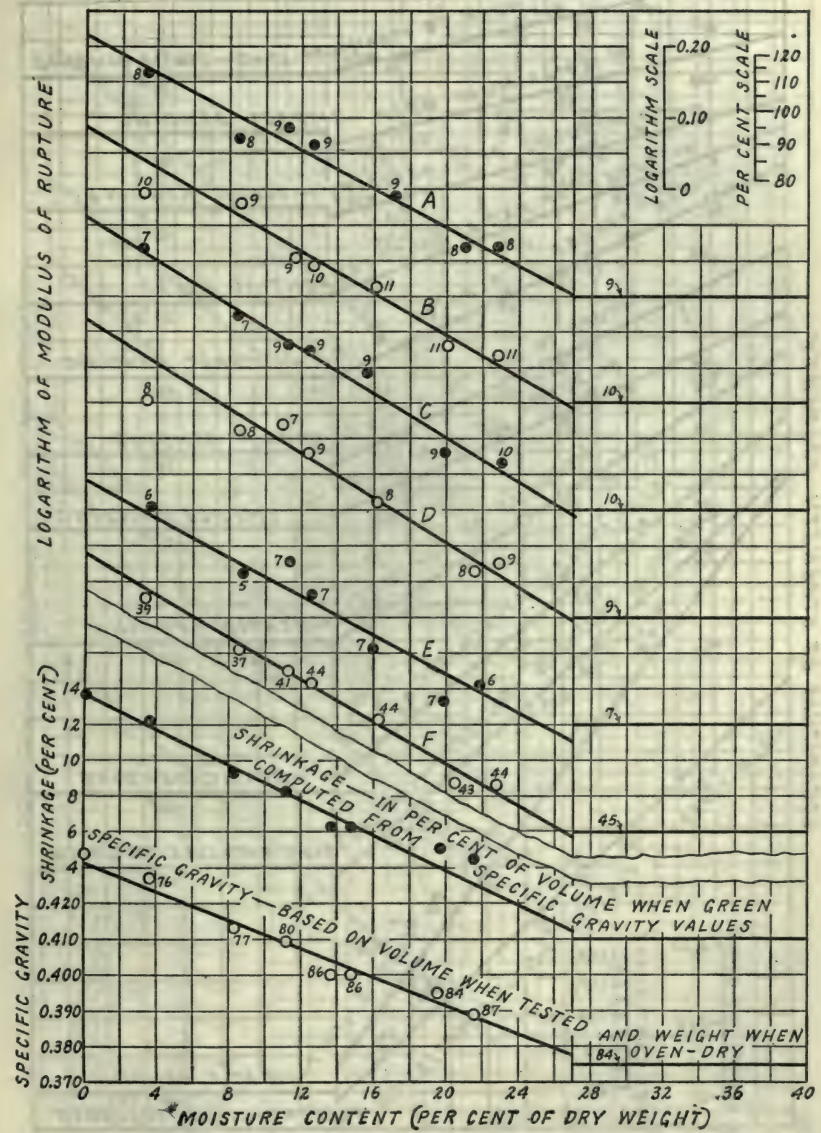

FIGURE 18.—Sitka spruce: Relation of average values of modulus of rupture by individual trees and of specific gravity and shrinkage in volume to moisture content. Numerals at points and on horizontal lines are numbers of tests averaged. Letters *A* to *E* each designate data for specimens from one tree. *F* is data for all trees combined and is identical with the modulus of rupture graph shown in Figure 14. For detailed data see Table 10

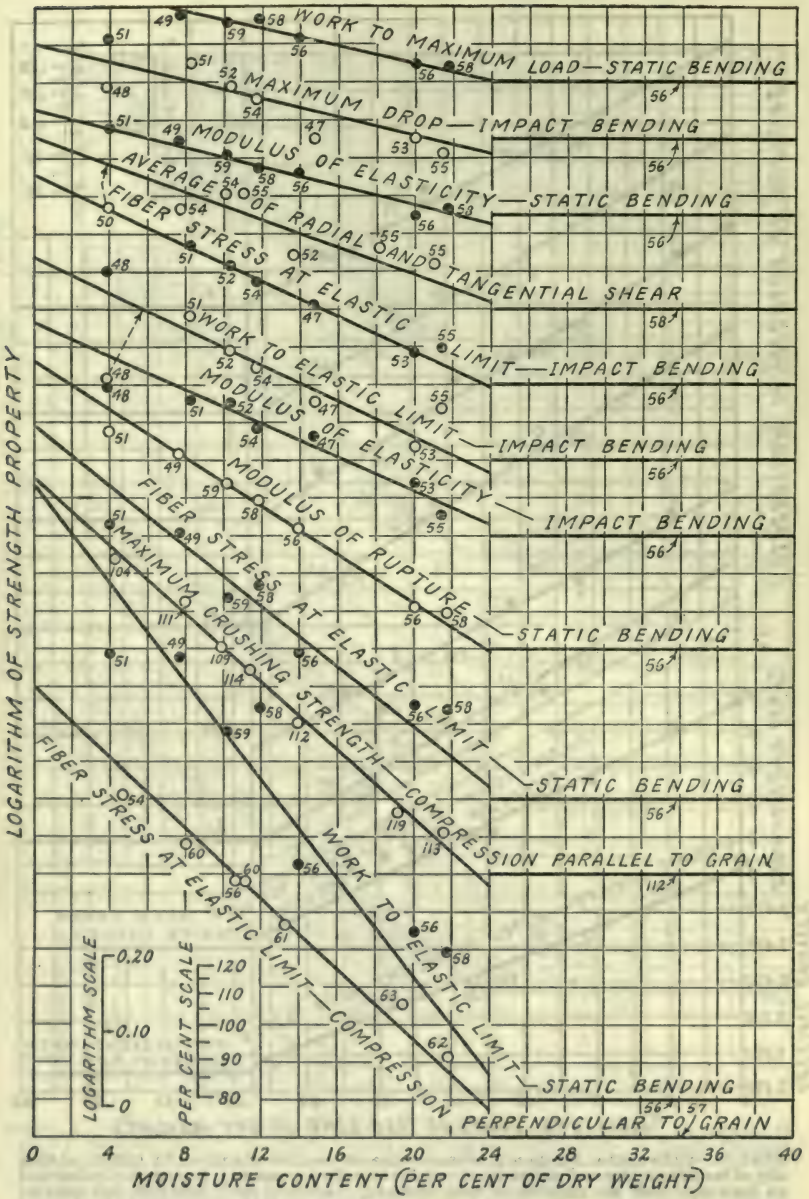

FIGURE 19.—Douglas fir: Relation of average values of various strength properties to moisture content. Numerals at plotted points and on horizontal lines are numbers of tests averaged. For detailed data see Table 11

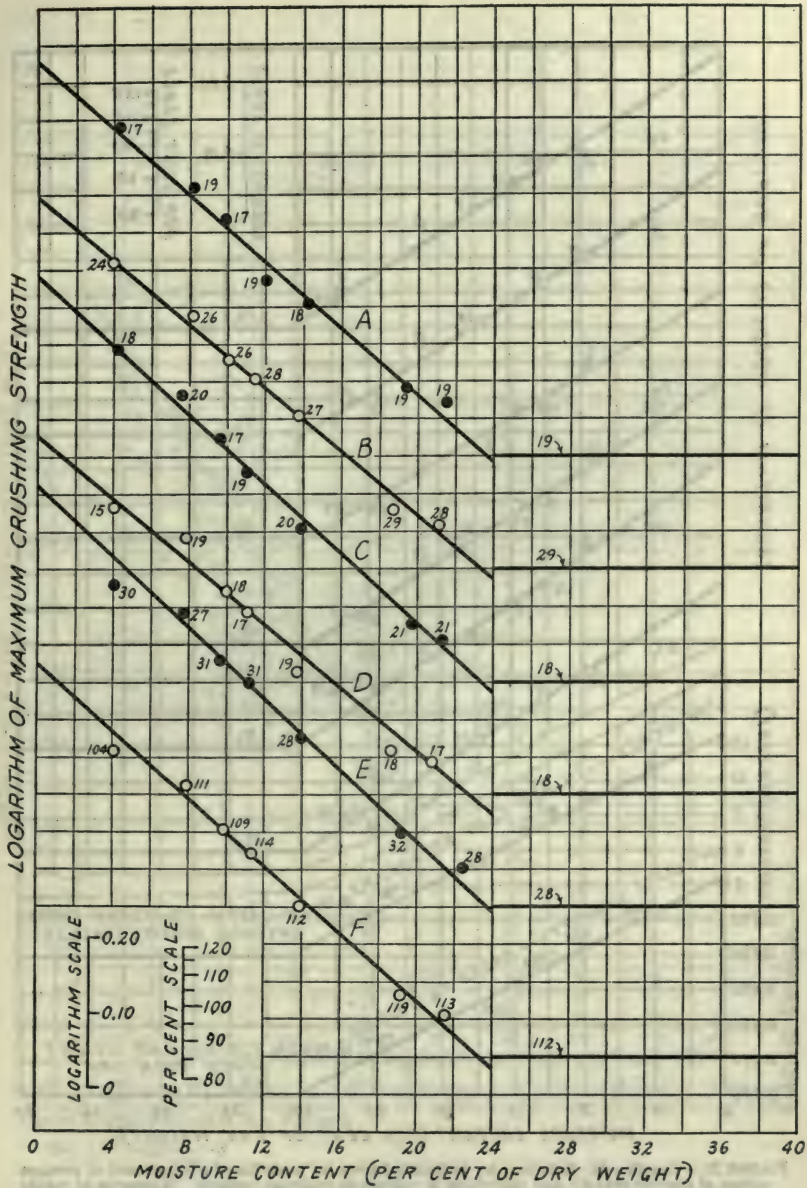

FIGURE 20.—Douglas fir: Relation, by individual trees, of maximum crushing strength in compression parallel to grain to moisture content. Numerals at plotted points and on horizontal lines are numbers of tests averaged. Letters *A* to *E* each designate data for specimens for one tree. *F* is data for all trees combined and is identical with maximum crushing strength shown in Figure 19. For detailed data see Table 12

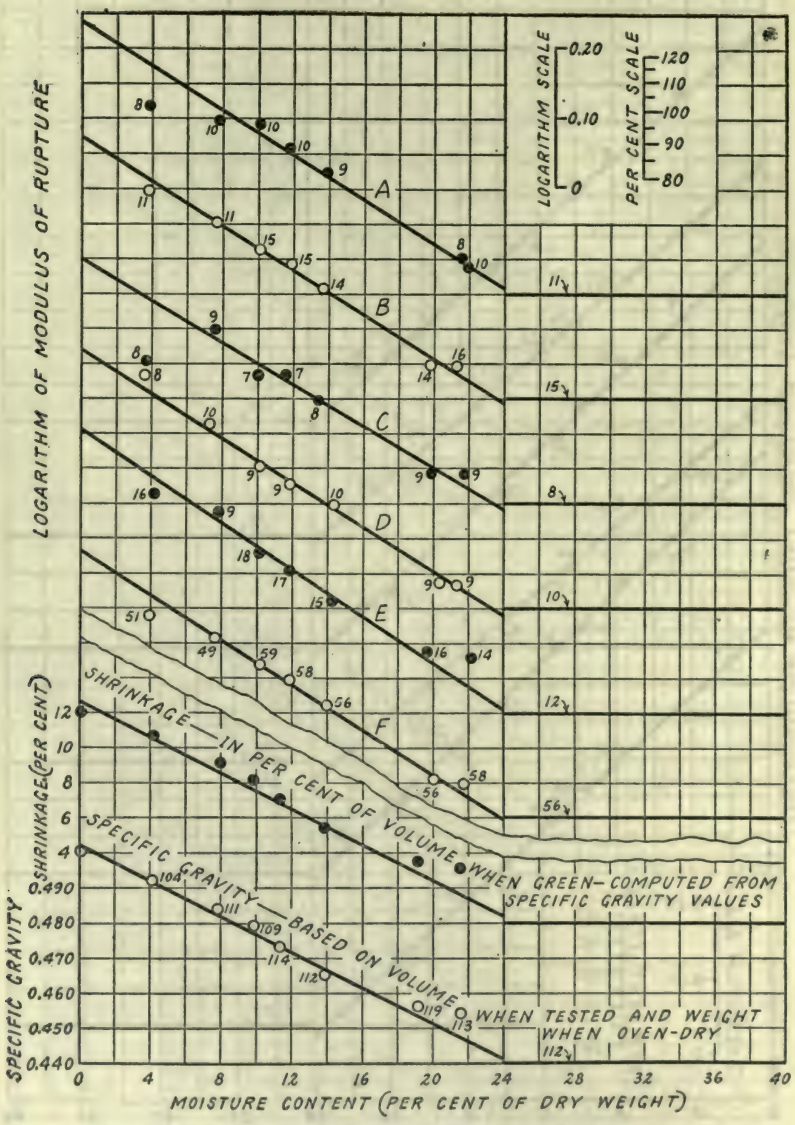

FIGURE 21.—Douglas fir: Relation, by individual trees, of modulus of rupture and of average values of specific gravity and shrinkage in volume to moisture content. Numerals at points and on horizontal lines are numbers of tests averaged. Letters *A* to *E* each designate data for specimens from a single tree. *F* is data for all trees combined and is identical with the modulus of rupture graph shown in Figure 19. For detailed data see Table 13

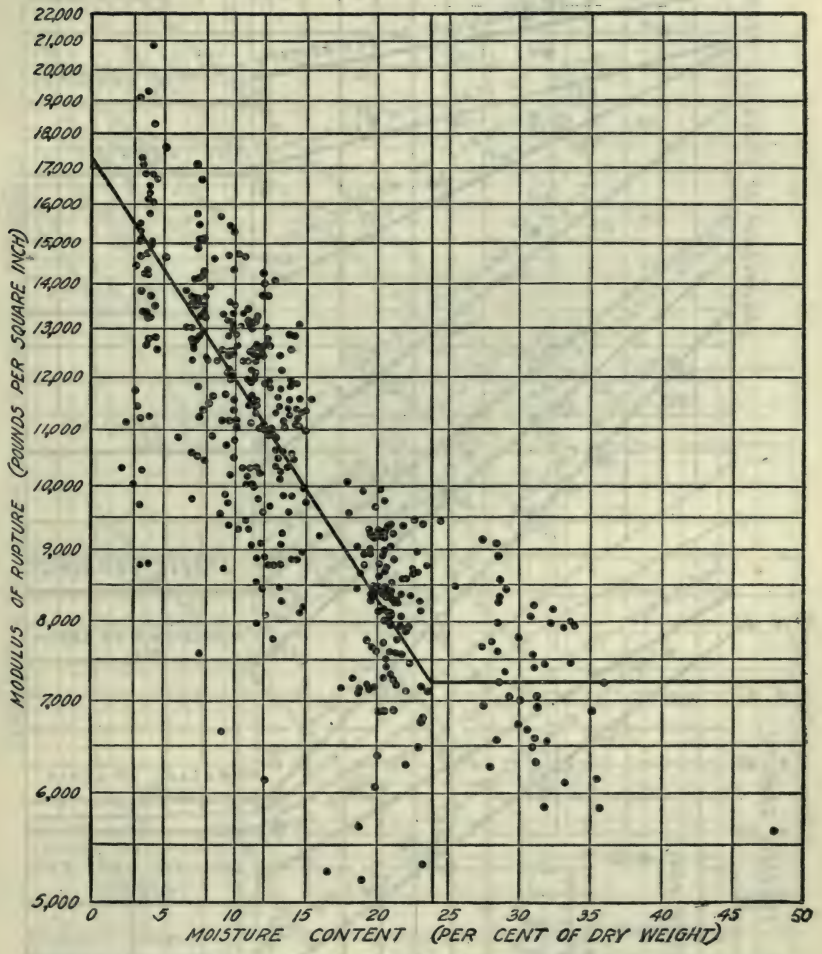

FIGURE 22.—Douglas fir: Relation, by individual specimens, of modulus of rupture to moisture content. The inclined and horizontal lines are identical with those for modulus of rupture shown in Figure 19 and at *F* in Figure 21

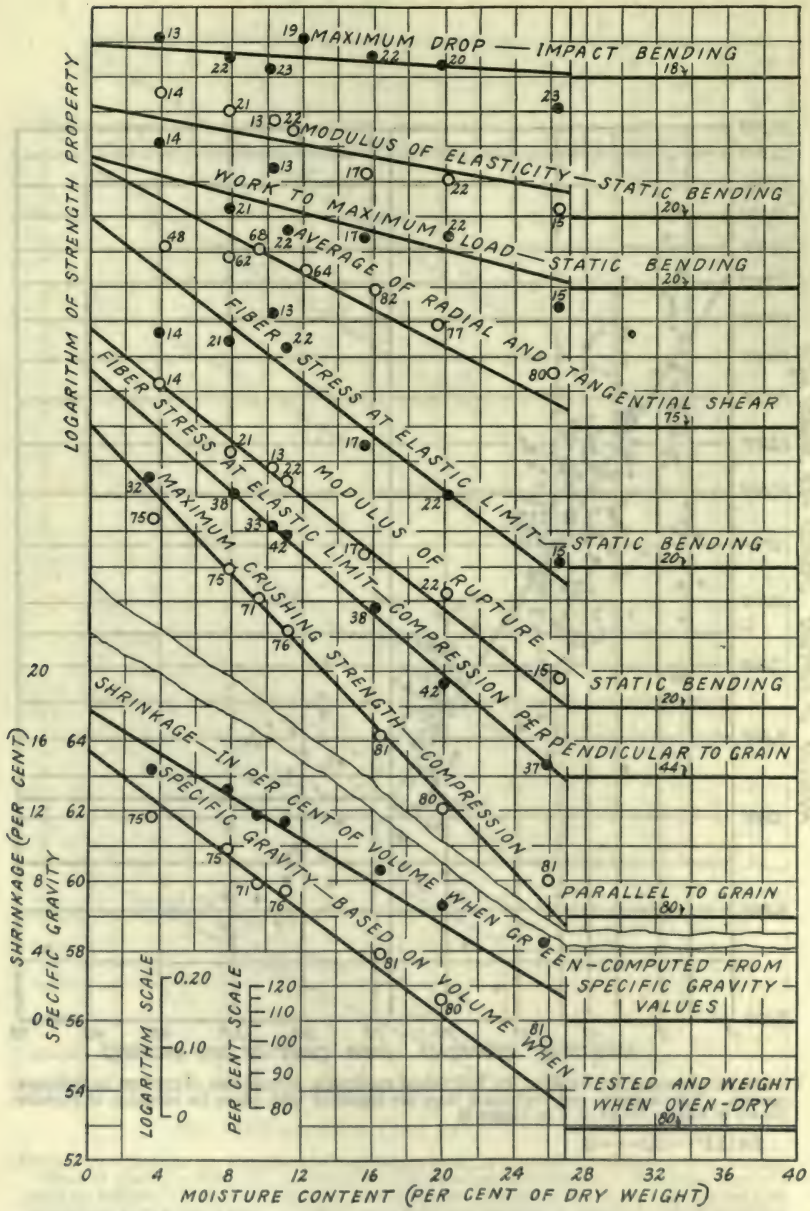
LOGARITHM OF STRENGTH PROPERTY
MAXIMUM DROP — IMPACT BENDING
MODULUS OF ELASTICITY — STATIC BENDING
WORK TO MAXIMUM LOAD — STATIC BENDING
AVERAGE OF RADIAL AND TANGENTIAL SHEAR
FIBER STRESS AT ELASTIC LIMIT — STATIC BENDING
MODULUS OF RUPTURE — STATIC BENDING
MAXIMUM CRUSHING STRENGTH — COMPRESSION PERPENDICULAR TO GRAIN
COMPRESSION PARALLEL TO GRAIN
SHRINKAGE — IN PER CENT OF VOLUME WHEN GREEN — COMPUTED FROM SPECIFIC GRAVITY VALUES
SPECIFIC GRAVITY — BASED ON VOLUME WHEN TESTED AND WEIGHT WHEN OVEN-DRY
LOGARITHM SCALE
PER CENT SCALE
SHRINKAGE (PER CENT)
SPECIFIC GRAVITY
MOISTURE CONTENT (PER CENT OF DRY WEIGHT)

FIGURE 23.—Yellow birch: Relation of average values of various strength properties, specific gravity, and shrinkage to moisture content. Numerals at points and on horizontal lines are numbers of tests averaged. For detailed data see Table 14

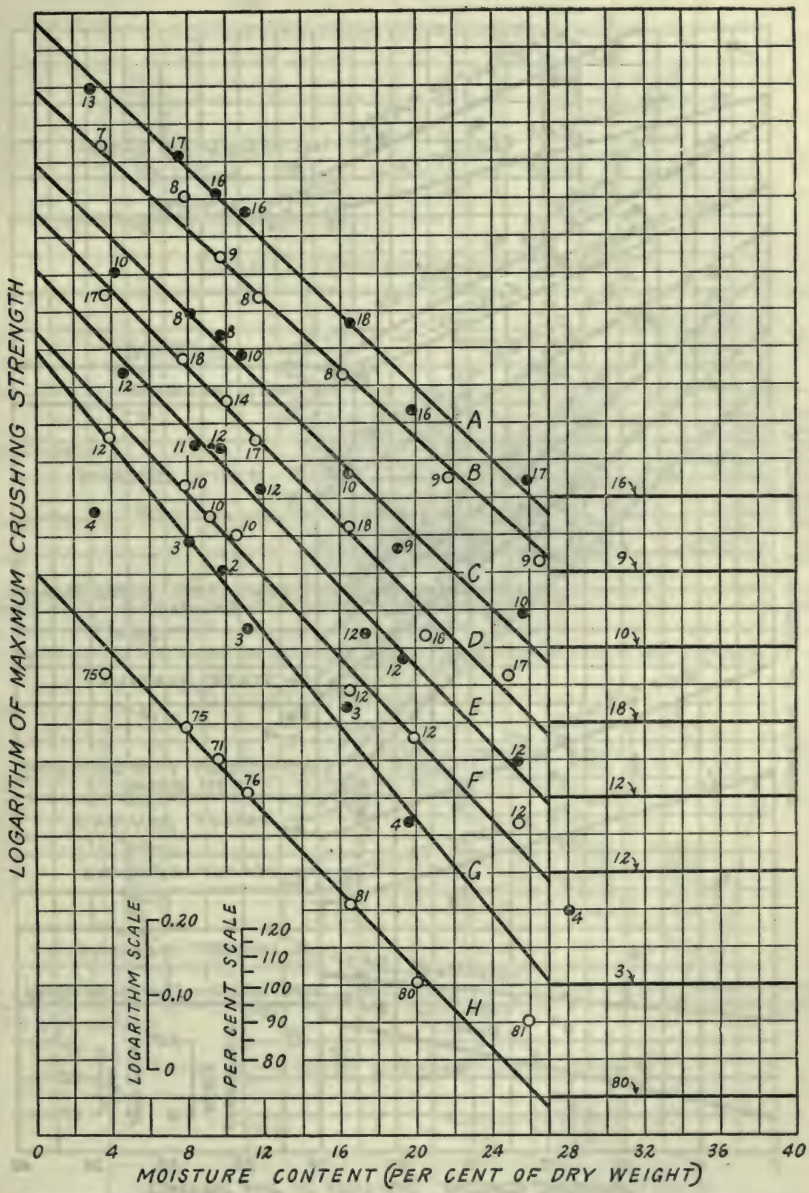

FIGURE 24.—Yellow birch: Relation, by individual trees, of maximum crushing strength in compression parallel to grain to moisture content. Numerals at points and on horizontal lines are numbers of tests averaged. Letters *A* to *G* each designate data for specimens from one tree. *H* is data for all trees combined and is identical with maximum crushing strength shown in Figure 23. For detailed data see Table 15

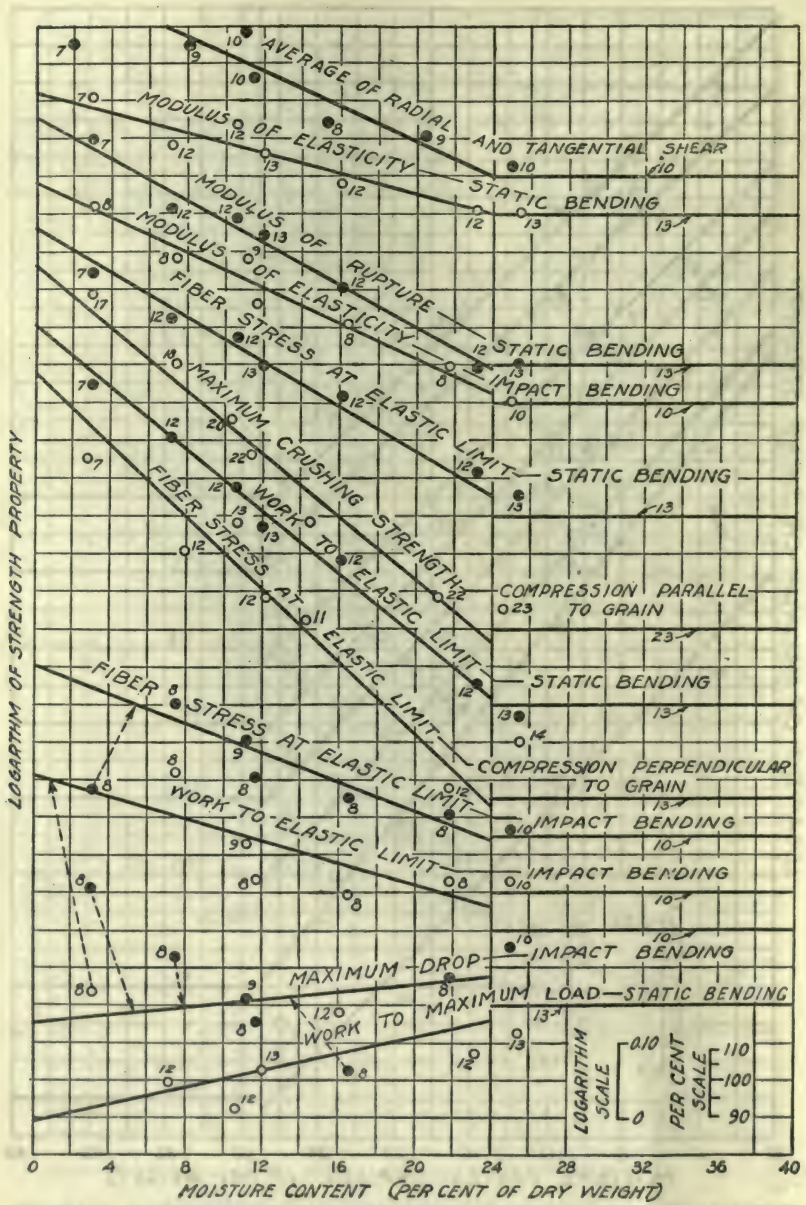
AVERAGE OF RADIAL AND TANGENTIAL SHEAR
MODULUS OF ELASTICITY — STATIC BENDING
MODULUS OF RUPTURE — STATIC BENDING
MODULUS OF ELASTICITY — IMPACT BENDING
FIBER STRESS AT ELASTIC LIMIT — STATIC BENDING
MAXIMUM CRUSHING STRENGTH — COMPRESSION PARALLEL TO GRAIN
WORK TO ELASTIC LIMIT — STATIC BENDING
FIBER STRESS AT ELASTIC LIMIT — COMPRESSION PERPENDICULAR TO GRAIN
FIBER STRESS AT ELASTIC LIMIT — IMPACT BENDING
WORK TO ELASTIC LIMIT — IMPACT BENDING
MAXIMUM DROP — IMPACT BENDING
MAXIMUM LOAD — STATIC BENDING
WORK TO
LOGARITHM OF STRENGTH PROPERTY
LOGARITHM SCALE
PER CENT SCALE
0 4 8 12 16 20 24 28 32 36 40
MOISTURE CONTENT (PER CENT OF DRY WEIGHT)

FIGURE 25.—White ash: Relation of average values of various strength properties to moisture content. Numerals at plotted points are numbers of tests averaged. For detailed data see Table 16

TABLE 10.—*Data pertaining to Figure 18* [1]

Tree	Reference letter	Average value	*K*
		Lbs. per sq. in.	
No. 1	A	5,945	0.0136
No. 3	B	6,355	.0147
No. 4	C	5,700	.0155
No. 5	D	5,780	.0157
No. 6	E	7,570	.0136
Average	F	6,200	.0147

[1] Average specific gravity for each tree is given in Table 8.

TABLE 11.—*Data pertaining to Figure 19*

Kind of test	Property	Average value [1] for green specimens	*K*
Static bending	Work to maximum load	7.48	0.0058
	Modulus of elasticity	1,477,000	.0063
	Modulus of rupture	7,235	.0160
	Fiber stress at elastic limit	3,840	.0200
	Work to elastic limit	0.61	.0326
Impact bending	Maximum drop	23	.0062
	Fiber stress at elastic limit	9,300	.0117
	Work to elastic limit	3.35	.0120
	Modulus of elasticity	1,456,000	.0112
Shear	Average of radial and tangential shearing stress.	810	.0091
Compression parallel to grain	Maximum crushing strength	3,730	.0225
Compression perpendicular to grain	Fiber stress at elastic limit	470	.0234

[1] Work values in inch-pounds per cubic inch; drop in inches; others in pounds per square inch.

TABLE 12.—*Data pertaining to Figure 20*

Tree	Reference letter	Specific gravity [1]	Average value	*K*
			Lbs. per sq. in.	
No. 1	A	0.492	3,680	0.0224
No. 2	B	.492	4,000	.0213
No. 3	C	.459	3,330	.0232
No. 4	D	.510	4,150	.0211
No. 5	E	.529	3,480	.0238
Average	F	.500	3,730	.0225

[1] Average value for all specimens tested. Based on weight and volume when oven dry. The average specific gravity based on weight when oven dry and volume when green was 0.442 for all specimens tested in the green condition.

TABLE 13.—*Detailed data pertaining to Figure 21* [1]

Tree	Reference letter	Average value	*K*
No. 1	A	7,290	0.0159
No. 2	B	7,440	.0159
No. 3	C	6,430	.0150
No. 4	D	7,590	.0158
No. 5	E	7,170	.0167
Average	F	7,235	.0160

[1] Average specific gravity for each tree is given in Table 8.

TABLE 14.—*Data pertaining to Figure 23*

Kind of test	Property	Average value [1] for green specimens	*K*
Impact bending	Maximum drop	33	0.0015
Static bending	Modulus of elasticity	1,395,000	.0045
	Work to maximum load	11.51	.0065
	Fiber stress at elastic limit	4,380	.0194
	Modulus of rupture	7,400	.0199
Shear	Average of radial and tangential shear	1,042	.0131
Compression perpendicular to grain	Fiber stress at elastic limit	625	.0216
Compression parallel to grain	Maximum crushing strength	2,890	.0265

[1] Drop in inches; work values in inch-pounds per cubic inch; others in pounds per square inch.

TABLE 15.—*Data pertaining to Figure 24*

Tree number	Reference letter	Average value for green specimens	*K*	Tree number	Reference letter	Average value for green specimens	*K*
No. 3	A	2,690	0.0244	No. 6	F	2,970	0.0273
No. 2	B	2,800	.0232	No. 4	G	2,340	.0313
No. 8	C	3,500	.0250				
No. 7	D	2,660	.0260	Average	H	2,890	.0265
No. 1	E	3,190	.0266				

TABLE 16.—*Data pertaining to Figure 25*

Kind of test	Property	Average value [1] for green specimens	*K*
Shear	Average of radial and tangential shearing stress.	1,280	0.0115
Static bending	Modulus of elasticity	1,215,000	.0066
	Modulus of rupture	8,335	.0138
	Fiber stress at elastic limit	4,010	.0148
	Work to elastic limit	0.90	.0206
	Work to maximum load	15.18	−.0057
Impact bending	Modulus of elasticity	1,333,000	.0116
	Fiber stress at elastic limit	9,800	.0096
	Work to elastic limit	4.08	.0073
	Maximum drop	37	−.0026
Compression parallel to grain	Maximum crushing strength	3,320	.0208
Compression perpendicular to grain	Fiber stress at elastic limit	805	.0238

[1] Work values in inch-pounds per cubic inch; maximum drop in inches; others in pounds per square inch.

DISCUSSION OF DATA AND COMPARISON WITH EXPONENTIAL FORMULA

The particular form (p. 13) in which the data are shown in Figures 7 to 25 was chosen because it seems from careful study that the exponential formulas, as previously discussed, represent experimental results more accurately than formulas of any other simple type, and because by such plotting graphs of formulas of the exponential type become straight lines. The data are presented in considerable detail in order to show just how good the representation is.

A vertical percentage scale has been placed on most of the diagrams in addition to the logarithmic scale. This vertical scale applies at any place on the sheet, and the percentage deviation of a plotted point from the line drawn to average the series of points to which it belongs can be estimated by superimposing the 100 per cent point of the scale on the average line. In figures having such vertical scales the points of each series are plotted with respect to a different

zero of the vertical scale. The zero for each graph is the average value from tests of green, or in a few instances, soaked, specimens. In other words, the values actually plotted are logarithms of the ratios $\frac{S}{S_p}$, where S and S_p are as defined in connection with equations (5) to (9).

DATA FROM GROUP 2 TESTS

Inasmuch as the tests of Group 2 were made with special reference to comparison with the exponential formula, the data from them will be considered first.

Figure 14 for Sitka spruce shows average values of each property for each of the several moisture-content classes. Reference to the exponential equation in the form of equation (8) or (9) shows that the values of three constants, or parameters, are required to fit this equation to a particular group of test values. One of these is K, the slope of the line that averages the points to the left of its intersection with the line representing the strength of green wood. The other two required parameters are M_p, the moisture content at the intersection point, and S_p, the strength value for green wood. S_p is presumably afforded directly by the test value from green specimens, but, as is shown later, this test value is subject to correction.

Inspection of any of the plots, such as Figure 14, shows that if the inclined lines that average the several series of plotted points are drawn to their intersections with the horizontal lines representing the strength values for green material, the several intersections will be at different values of M. In other words, a variety of values of M_p will be indicated even for properties derived from the same test, such as fiber stress at elastic limit, modulus of rupture, modulus of elasticity, work to elastic limit, and work to maximum load, all of which are determined from static bending tests. Although it is possible that the value of M_p is not the same for all properties, the variety of values of M at the apparent intersection points is explainable on the basis of lack of perfect matching between groups of specimens tested at different moisture-content values, this deficiency of matching probably having a different effect on different strength properties. Had the matching of specimens actually averaged out (p. 23) the effect of all factors other than moisture content and if the assumed exponential law holds true, all the plotted points of a series would lie on a straight line. The fact that the plotted points do not follow a straight line or a smooth curve indicates that the relations between strength values are influenced by factors other than that of differences in the moisture content of the test specimens.

When allowance is made for the lack of perfect matching among the several moisture-content sets, it is possible to derive from the data on each species a value of M_p that is acceptable for all of the strength properties.[8]

Values of M_p for Sitka spruce, Douglas fir, yellow birch, and white ash were determined from the strength data shown in Figures 14, 19, 23, and 25 by a least-squares computation. In making this computation points representing the sets of specimens tested at the lowest moisture content were omitted because the tendency, observed in some instances, for these points to fall below the inclined lines averaging other points of the same series suggested either that drying to

[8] Convenience in the use of formulas for moisture-strength adjustment, as is shown later, makes a single value of M_p for all properties of a species desirable.

so low a moisture content had resulted in injury to the strength properties or that the assumed straight-line relation between percentage of moisture content and the logarithm of the strength property would not hold for very low moisture-content values. Data from the sets of specimens tested at the highest moisture content below the green condition were also omitted because, in spite of the care taken in conditioning specimens, it has not been possible to bring about in this set the desired uniformity of distribution of moisture between parts of the same specimen and between different specimens. These two classes of points represent moisture-content values that are outside the range to which chief interest attaches in connection with moisture-strength adjustments. The M_p vertical and the several inclined lines in Figure 14 were so located as to make the sum (for the entire figure) of the squares of the vertical deviations of the plotted points, exclusive of those omitted for reasons just stated, and of the points at the intersections of the horizontal lines with the M_p vertical a minimum except that location of M_p at fractional values of moisture-content percentages was not considered. The same procedure was followed in locating the M_p verticals and fitting the inclined lines to the data on strength properties in Figures 19, 23, and 25.

In Figures 15, 18, 20, 21, and 24 are presented data on maximum crushing strength for individual trees of Douglas fir, Sitka spruce, and yellow birch, and on modulus of rupture for individual trees of Douglas fir and Sitka spruce. Similar diagrams are not shown for other properties and species because the number of tests from individual trees is not sufficient to afford reliable averages.

The inclined lines in these diagrams (figs. 15, 18, 20, 21, and 24) were located by least-squares methods, the strength values for green material being assumed to obtain at the value of M_p previously found for the respective species.

In Figures 16 and 22 are plotted individual test values for maximum crushing strength of Sitka spruce and modulus of rupture of Douglas fir, respectively. Each of these figures shows a comparatively large variation in strength values for green specimens and a somewhat larger variation for specimens at moisture-content values below M_p. This indicates that the major portion of the variation in strength at any moisture content value below M_p is due to variation in the inherent strength of the wood, the remainder being the result of variations in the effect of drying.

It has been shown (*8*) that there is a reasonably good correlation between specific gravity and strength properties of wood. Consequently, it is to be expected that the variations in strength values exhibited by Figures 16 and 22 would be reduced if the range in specific gravity of specimens were reduced. In Figure 17 the result of classifying the data of Figure 16 into four groups according to the specific gravity of the specimens is shown.

In assembling the data for this figure the seasoned specimens were first divided into groups within each of which there was only a comparatively small range of moisture-content values. The specimens of each of these groups were then arranged in order of their specific-gravity values and were divided into four subgroups A, B, C, and D, each of which comprised an approximately equal number of tests, subgroup A including the specimens of highest specific gravity. The subgroup averages for maximum crushing strength and moisture content, as well as the individual test values are plotted in Figure 17.

The inclined lines shown in this figure have been fitted to the subgroup averages by least-squares computations, assuming the green values to obtain at 27 per cent moisture, which is the value of M_p previously determined for Sitka spruce.

All the data for specimens below 25 per cent moisture content were used because in this instance there is little or no evidence that the material near the upper limit of moisture content has been influenced by unequal moisture distribution or that that near the lower limit has been adversely affected by drying to so low a moisture content.

The variability of maximum crushing strength for green specimens or for specimens at any moisture content below the M_p value is readily seen to be considerably less in each section of Figure 17 than in Figure 16, showing that the classification of specimens according to their specific gravity has reduced the variability in the strength value. It remains true of each part of Figure 17, however, as of Figure 16, that the variation of strength at moisture-content values below M_p is greater than the variation in strength of green material, indicating that part of the variability at moisture-content values below M_p is due to variability in the effect of drying.

DATA FROM GROUP 1 TESTS

The data from Group 1 tests are shown in Figures 8 to 13. The M_p vertical and the inclined lines in Figure 8 (longleaf pine) were located by the method described in connection with Figure 14. This was considered better than to rely on the tests on small specimens for determination of the interesection point as advocated in the previously quoted excerpts (p. 13) because Figure 8 (2 by 2 inch specimens) includes data for a variety of moisture-content values between zero and the intersection point, whereas the smaller specimens (fig. 13) were tested only at values near the fiber-saturation point and at comparatively low moisture-content values.

Data on loblolly pine are available only for the small specimens. (Fig. 13.) These were tested at moisture-content values near the fiber-saturation point and at low moisture-content values. Taking only those points representing a moisture content below 20 per cent, the least-squares computation indicates a value of nearly 22 per cent for M_p. However, the points just below 20 per cent may be raised slightly by nonuniform drying of specimens, and this would tend to increase the computed value of M_p. Furthermore, it might be expected that loblolly pine would be quite similar to longleaf pine with respect to moisture content at the intersection point, and since Figure 8 indicates 21 per cent as the best value for longleaf, this value is taken for loblolly pine also. Information from shrinkage tests presented later is further evidence of the similarity of longleaf and loblolly pines with respect to moisture content at the intersection point.

In determining a value of M_p for red spruce, principal reliance was placed on the data on maximum crushing strength (figs. 9, 10, and 13) and on fiber stress at elastic limit in compression parallel to grain. (Figs. 9 and 10.) These data indicate a value of 27 per cent for M_p—the same value as found for Sitka spruce, to which red spruce is very similar in many other properties. (A value of 30 per cent for M_p of red spruce is indicated by Figure 7. This figure, however, shows points taken from the curves originally drawn to represent the data, whereas the value of 27 per cent has been determined from a study of the actual test data as plotted in Figures 9, 10, and 13.)

The data on maximum crushing strength (fig. 11 for 2 by 2 inch specimens and fig. 12 for smaller specimens) were used in determining M_p for chestnut, and a value of 24 per cent was found.

ADDITIONAL DATA

Tests, additional to those of Groups 1 and 2, are presented in Figures 26 and 27. Figure 26 is data on maximum crushing strength in

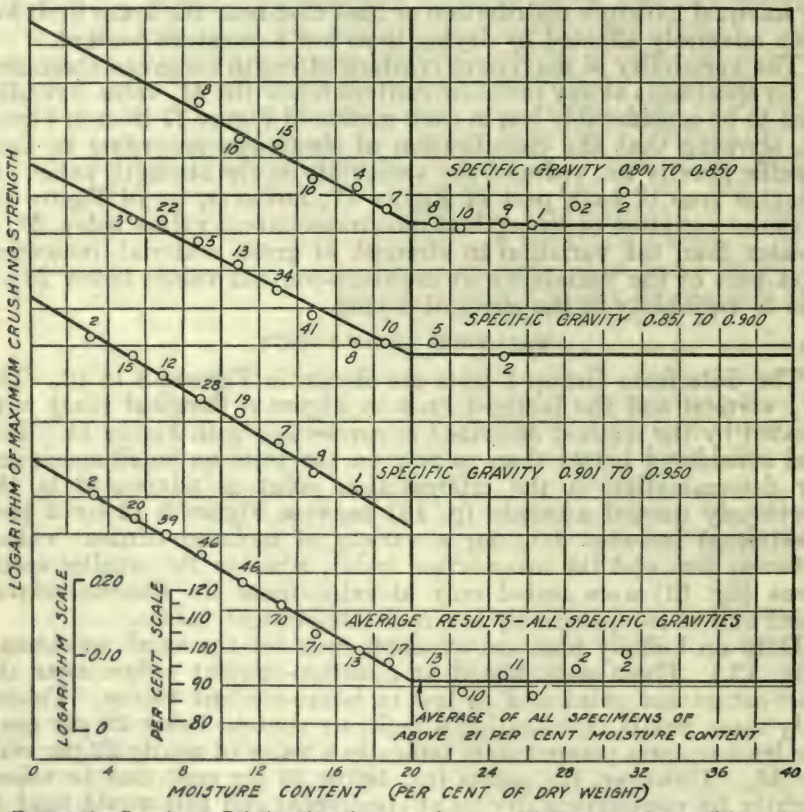
LOGARITHM OF MAXIMUM CRUSHING STRENGTH
SPECIFIC GRAVITY 0.801 TO 0.850
SPECIFIC GRAVITY 0.851 TO 0.900
SPECIFIC GRAVITY 0.901 TO 0.950
AVERAGE RESULTS—ALL SPECIFIC GRAVITIES
AVERAGE OF ALL SPECIMENS OF ABOVE 21 PER CENT MOISTURE CONTENT
LOGARITHM SCALE
PER CENT SCALE
MOISTURE CONTENT (PER CENT OF DRY WEIGHT)

FIGURE 26.—Greenheart: Relation of maximum crushing strength in compression parallel to grain to moisture content. Specimens were 1 by 1 by 2¾ inches. Numerals at points are numbers of tests averaged. The average results curve includes data from specimens with specific gravity values below 0.801 and above 0.950.

compression parallel to the grain derived from tests on 1 by 1 by 2¾ inch specimens of greenheart (*Nectandra rodioei*). These data show exceptionally good conformity to a straight-line relation. Figure 27 exhibits moisture relations for modulus of rigidity, shear stress at elastic limit, and ultimate shear stress as found from torsion tests of Sitka spruce (*14*).

SUMMARY OF DATA AND DISCUSSION

The relation of moisture content to mechanical properties of wood has been pictured in Figures 8 to 27 and compared to the exponential formula for all series of tests for which original data are available. Data on 22 mechanical properties and 9 species of wood are included.

In general, it may be said that the agreement of experimental data with the exponential formula is sufficiently good to justify the belief that with the proper values of K and M_p this formula will represent

the relation between moisture content, over a considerable part of the range between zero and the fiber-saturation-point value and any mechanical property for any species of wood very accurately.[9]

It is evident from the data presented that both K and M_p vary, and before discussing the use of the exponential formula in adjusting test results, it will be well to consider the variations in these parameters and to compare values of M_p with fiber-saturation-point moisture-content and similar values as derived from other experimental data.

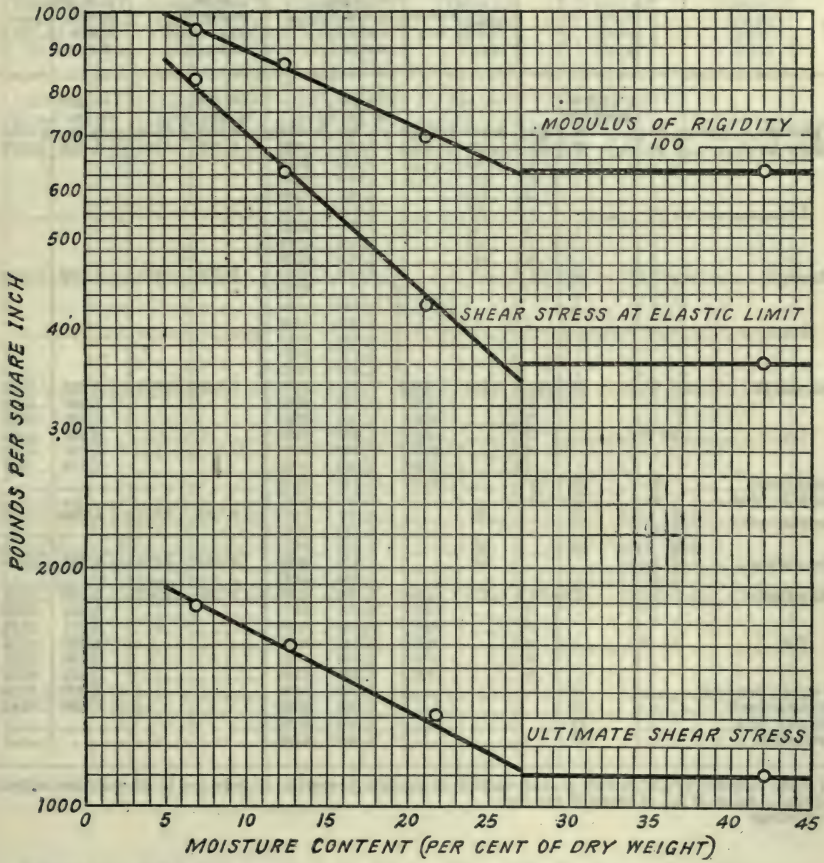

FIGURE 27.—Sitka spruce: Relation of properties obtained from torsion tests to moisture content. Each plotted point represents three tests. Values of K for modulus of rigidity, shear stress at elastic limit, and ultimate shear stress are 0.0092, 0.0184, and 0.0105, respectively

Values of M_p for the species included in Figures 8 to 27 and of K for several properties of these species are assembeled in Table 17.[10] M_p is seen to vary with the species, the range shown being from 20 to 27 per cent moisture. As accurate adjustment of test results for differences in moisture content (p. 66) requires accurate values for M_p, some method by which such values can be found without an elaborate series of mechanical tests is obviously very desirable.

[9] It is interesting to note in this connection that for moisture content values below the fiber-saturation point the specific electrical conductance of wood conforms to a similar law. (P. 57.)

[10] Table 17 includes information on four species additional to those previously discussed. The values listed for these four species were derived from data taken from average curves constructed by the original investigators, the original test data not being available (*4, 5, 13*).

TABLE 17.—*Results of tests of the effect of*

Species	Figure	[1] M_p	Tree No.	Specific gravity of specimens—based on weight when oven-dry and volume when—		Compression parallel to grain (maximum crushing strength)		Static bending			
								Fiber stress at elastic limit		Modulus of rupture	
				Green	Oven-dry	Value for green specimens	K	Value for green specimens	K	Value for green specimens	K
		Per cent moisture				*Lbs. per sq. in.*		*Lbs. per sq. in.*		*Lbs. per sq. in.*	
White ash	25	24	[2]	0.490	0.575	3,320	0.0208	4,010	0.0148	8,335	0.0138
Yellow birch	23	27	[2]	.529	------	2,890	.0265	4,380	.0194	7,400	.0199
Do	24	------	1	.543	------	3,190	.0266	------	------	------	------
			2	.511	------	2,800	.0232				
			3	.519	------	2,690	.0244				
			4	.497	------	2,340	.0313				
			6	.552	------	2,970	.0273				
			7	.535	------	2,660	.0260				
			8	.545	------	3,500	.0250				
Chestnut	11	24	[2]	.43	------	3,070	.0214	3,570	.0187	6,270	.0132
Do	12	------	------	------	------	------	.0218	------	------	------	------
						2,420	.0294				
						2,360	.0236				
						4,015	.0203				
						3,135	.0197				
						4,480	.0185				
Douglas fir	19	24	[2]	.440	.500	3,730	.0225	3,840	.0200	7,235	.0160
Do	20, 21	------	1	------	.492	3,680	.0224	------	------	7,290	.0159
			2	------	.492	4,000	.0213	------	------	7,440	.0155
			3	------	.459	3,330	.0232	------	------	6,430	.0150
			4	------	.510	4,150	.0211	------	------	7,590	.0158
			5	------	.529	3,480	.0238	------	------	7,170	.0167
Greenheart	26	20	[3]	------	.875	10,130	.0149	------	------	------	------
Loblolly pine	13	21	[3]	------	------	2,010	.0247	------	------	------	------
Longleaf pine	8	21	------	.56	------	4,605	.0257	4,920	.0245	8,890	.0210
	13	------	------	------	------	5,720	.0207	------	------	------	------
Red spruce	9	27	------	.36	------	2,620	.0234	------	------	------	------
	10	------	------	.38	------	2,410	.0229	3,160	.0176	5,165	.0166
	13	------	------	------	------	2,580	.0217	------	------	------	------
Sitka spruce	14	27	[3]	.375	.439	3,070	.0200	3,755	.0161	6,200	.0147
Do	15, 18	------	1	------	.439	2,835	.0213	------	------	5,945	.0136
			3	------	.461	3,230	.0199	------	------	6,355	.0147
			4	------	.405	2,845	.0196	------	------	5,700	.0155
			5	------	.416	2,870	.0212	------	------	5,780	.0157
			6	------	.476	3,735	.0184	------	------	7,570	.0136
Western hemlock	------	28	------	------	------	3,250	.0192	------	------	7,200	.0139
Western larch	------	28	------	------	------	3,900	.0190	------	------	7,600	.0143
Norway pine	------	24	------	------	------	1,800	.0260	------	------	------	------
Tamarack	------	24	------	------	------	3,200	.0246	------	------	------	------

[1] Some recently available data on the relation of strength properties of redwood to its moisture content indicate a value of M_p of about 21 per cent.

[2] Average

moisture on the strength properties of wood

Static bending						Compression perpendicular to grain (fiber stress at elastic limit)		Shear parallel to grain (average of radial and tangential shear)		Impact bending (drop required to cause failure 50-pound hammer)	
Modulus of elasticity		Work to elastic limit		Work to maximum load							
Value for green specimens	*K*	Value for green specimens	*K*	Value for green specimens	*K*	Value for green specimens	*K*	Value for green specimens	*K*	Value for green specimens	*K*
1,000 lbs. per sq. in.		*In.-lbs. per cu.in.*		*In.-lbs. per cu.in.*		*Lbs. per sq. in.*		*Lbs. per sq. in.*		*Inches*	
1,215	0.0066	0.90	0.0206	15.18	−0.0057	805	0.0238	1,280	0.0115	37	−0.0026
1,395	.0045			11.51	.0065	625	.0216	1,042	.0131	33	.0015
1,068	.0068							733	.0057		
1,477	.0063	.61	.0326	7.48	.0058	470	.0234	810	.0091	23	.0062
1,896	.0062	.73	.0396					915	.0157		
								677	.0105		
1,262	.0056							608	.0155		
1,371	.0060	.61	.0260	5.93	.0099	335	.0187	730	.0072	24	.0027
1,375	.0066										
1,350	.0070										

METHODS OF FINDING M_p

Methods that may be considered for finding or estimating M_p are: (1) Estimation from other properties and characteristics of the species; (2) simple mechanical tests; (3) physical measurements, such as shrinkage, electrical conductivity, and equilibrium moisture content.

ESTIMATION OF M_p FROM SPECIES CHARACTERISTICS AND FROM MECHANICAL TESTS

Inspection of Table 17 indicates that M_p is not definitely correlated with other tabulated characteristics of the species or of different series of specimens of the same species. For instance, no systematic relation to specific gravity or to the strength of the wood is apparent. Neither is there any indication that coniferous woods have value of M_p differing from those of the hardwood species. (The range of values shown is from 20 to 27 per cent for hardwoods.) Hence, it is quite improbable that an accurate estimate of the value of M_p can be had from a consideration of other characteristics of a species.

However, listing the species from Table 17 according to decreasing values of moisture content at the intersection point brings out some interesting relationships. The list is as follows:

Species	M_p	Species	M_p
Western larch	28	White ash	24
Western hemlock	28	Chestnut	24
Sitka spruce	27	Douglas fir	24
Red spruce	27	Norway pine	24
Yellow birch	27	Tamarack	24
		Loblolly pine	21
		Longleaf pine	21
		Greenheart	20

Except western larch, the species in the first column have no well developed summer wood. Larch, moreover, is usually very fine ringed, which tends to give the wood a uniform structure. The species in the second column, except greenheart, have well-developed summer wood which differs from the spring wood in many respects. The suggestion from this listing is that wood structure of different types, even within a single species, may have different fiber-saturation points or intersection points.

The data on maximum crushing strength of Sitka spruce have been studied to determine whether they indicate a relation between M_p and the specific gravity of the wood.

As previously stated (p. 41) the inclined lines in each section of Figure 17 were fitted to the plotted points by a least-square computation, assuming the green values to obtain at 27 per cent moisture content, that is, assuming $M_p = 27$ per cent. If no assumption is made as to the value of M_p and straight lines are fitted to the subgroup averages for moisture-content values below 24 per cent, these lines intersect the horizontals representing the strength of green wood as follows: A at 25.3 per cent; B at 26.0 per cent; C at 27.4 per cent; and D at 27.4 per cent moisture content. These data afford a slight indication that M_p is lower for wood of high specific gravity. Similar analyses of the maximum crushing strength data for Douglas fir and yellow birch fail to disclose any relation between M_p and specific gravity.

As has been mentioned, the principal difficulty in getting accurate information on moisture-strength phenomena is that of obtaining close matching between specimens or groups of specimens for test at different moisture-content values. This makes necessary the testing of a considerable number of specimens in order to obtain reliable averages. A test or determination that would not damage or change the specimen would be advantageous in this connection, since it could be applied to a specimen in the green condition and to the same specimen following its conditioning to successively lower moisture-content values, thus eliminating the matching problem and reducing the number of specimens required. Mechanical properties that can be determined without damage to the specimen are modulus of elasticity and modulus of rigidity. A few determinations of modulus of elasticity were made on the same specimens at various moisture-content values in connection with the other tests of the Group 2 series. Six specimens of Douglas fir and one each of white ash and Sitka spruce were used. Unfortunately, determinations were not made on these specimens while they were green. Consequently, it is not possible from the results to find values of M_p to be compared with those derived from other tests so as to evaluate modulus of elasticity determinations as a means of locating the intersection point. Experience with the tests made indicates that more than ordinary care in the selection, preparation, and conditioning of the specimens, and more than ordinary accuracy in measuring deflections and the dimensions of specimens will be required to get satisfactory results from a few specimens. Modulus of elasticity determinations made on the same specimens in the green condition and again after drying the specimens to successively lower moisture-content values are apparently worthy of further investigation as a means of locating the intersection point. However, since M_p may vary with different pieces of the same species, it would be unsafe to rely on tests of a single specimen or of a few specimens.

If dependence is to be put on tests of a single mechanical property for determining the intersection point, maximum crushing strength in compression parallel to grain would be the first choice because it is most affected by changes of moisture content and consequently the effect of differences in moisture is less likely to be obscured by other uncontrolled factors. It should be noted, however, that maximum crushing strength taken alone would have fixed the intersection points for each of the four species included in Group 2 at slightly lower moisture-content values than are indicated by all the properties taken together. Specimens for this test can be of small size, and hence good matching can be obtained. In any such tests a considerable number of specimens for test at each of several degrees of moisture content are necessary. A number of series of specimens should be so selected as to cover reasonably well the range in the quality of the wood of the species.

ESTIMATION OF M_p FROM SHRINKAGE MEASUREMENTS

In connection with the tests of Group 2 very careful measurements were made of the shrinkage of specimens taken from the same logs as those for mechanical tests. These specimens were each weighed and measured in the green condition and then placed in a room in which

a relative humidity of about 90 per cent was maintained, where they were weighed and measured at frequent intervals until equilibrium was attained. Weights and measurements were similarly made after successive transfers to 60 per cent and to 30 per cent humidity rooms. Finally the specimens were weighed and measured after they had been dried to constant weight at 100° C. The specimens were 1 inch thick by 4 inches wide by 1 inch along the grain, the width being radial or tangential according to the direction of the shrinkage to be measured. Both radial and tangential measurements were made on an additional series of specimens of yellow birch 2 by 2 inches in cross section and one-fourth inch along the grain. The computed shrinkage and moisture-content values are shown in Figures 28 to 31, inclusive. These graphs show that in most instances measurable shrinkage occurred at a moisture content greater than the intersection-point value. In locating the inclined lines in these figures, only points representing decreasing moisture content have been considered; that is, points such as those numbered 10 in Figure 28, which represent moisture-content and shrinkage determinations made when the specimens had regained moisture after having been dried to a lower moisture content, have been disregarded. Except the one at zero moisture content, points representing decreasing moisture-content values below 16 per cent are very close to a straight line. Each inclined line in Figures 28 to 31 was located to pass through the point representing the lowest moisture content above zero and through the average of two points near 12 per cent moisture content. The validity of basing the location of these lines on the three points selected might be questioned. However, the effort has been to locate lines that will represent the shrinkage-moisture relation within the range of about 4 to 16 per cent moisture content. The points selected are the only ones available for this purpose, the two near 12 per cent moisture are in most instances almost exactly in line with that representing the lowest moisture content above zero, and the three points taken together quite definitely fix the position of the line representing the desired range. The percentages of moisture at the intersections of the inclined lines in Figures 28 to 31 with the horizontal lines representing zero shrinkage are taken as the intersection-point values.[11] (No question of lack of matching as previously considered in connection with the strength tests is involved because identical specimens were measured at different moisture-content values.) The intersection points as determined from the several sets of shrinkage-moisture data vary over a fairly wide range for each species. Heartwood and sapwood appear to differ, but neither consistently indicates higher intersection points. Hence, these data afford no basis for a generalization as to a comparison between heartwood and sapwood with respect to moisture content at the intersection point. On the contrary, tangential shrinkage measurements consistently indicate

[11] It has been demonstrated that the change in dimensions of wood of some hardwood species in drying from the green state to a low moisture content is greatly influenced by the relative humidity to which the wood is subjected. For example, twice as much decrease in cross-sectional area occurred in oak specimens dried at high relative humidities as in matched specimens dried to the same moisture content at practically the same temperature but at much lower humidities. Similar results have been observed in the drying of some other hardwoods. Apparently, the shrinkage of most softwood, or coniferous, species is influenced but little by the conditions under which drying takes place. What effect the humidity maintained during drying has on the intersection points in plots of shrinkage-moisture data has not been investigated.

higher values than do radial. This might be supposed to be due to the fact that measurements of shrinkage in the two directions were made on different specimens.[12] However, as shown by *C* and *D* of Figure 30, the same comparison obtains for tangential and radial measurements made on identical specimens of yellow birch. In additional series of shrinkage measurements (p. 54) it was quite consistently true that tangential shrinkage measurements indicated higher values than did radial.

Table 18 lists the values of moisture content at intersection points as found from the shrinkage data in Figures 28 to 31 and for comparison the average values found from mechanical tests. The value from mechanical tests of Sitka spruce is higher than that from shrinkage, whereas the reverse is true for the other three species. The conclusion from this comparison is that the value of moisture content at the intersection point in such plots of shrinkage-moisture data as are shown in Figures 28 to 31 does not coincide with the value of M_p obtained from mechanical-test data, but may in the absence of determinations of the latter kind be considered sufficiently reliable to be taken as a guide in estimating values of M_p for use in dealing with data on mechanical properties of species for which M_p has not been determined.

TABLE 18.—*Values of M_p from mechanical tests and percentage of moisture at intersection point from shrinkage measurements on the same species*

Species	Average value for M_p from mechanical tests	Percentage of moisture at intersection point—from shrinkage measurements						
		Tangential shrinkage			Radial shrinkage			Tangential and radial shrinkage (All specimens)
		Specimens of heartwood	Specimens of sapwood	All specimens	Specimens of heartwood	Specimens of mixed heartwood and sapwood	All specimens	
Sitka spruce	27	26.2	25.9	26.0	24.6	23.6	24.1	25.3
Douglas fir	24	25.6	27.3	26.2	26.0	25.4	26.0	25.8
Yellow birch	27			30.8			27.0	28.9
White ash	24	26.9	28.6	28.0	24.4	25.5	25.0	26.7

Table 19 lists intersection point-moisture content values obtained from other shrinkage-moisture data. Each species is represented in this table by shrinkage and moisture measurements on specimens 1 by 4 by 1 inches in dimension. Although these shrinkage determinations were carried out with less care and refinement than those represented in Table 18, the values given are believed to be reasonably reliable as determinations of the intersection point moisture from shrinkage data. Values in Tables 18 and 19 for species common to the two tables agree quite well, the greatest difference being about 3 per cent for white ash.

[12] In order to get the width more nearly tangential, the tangential specimens must ordinarily be taken further from the pith of the tree than the radial.

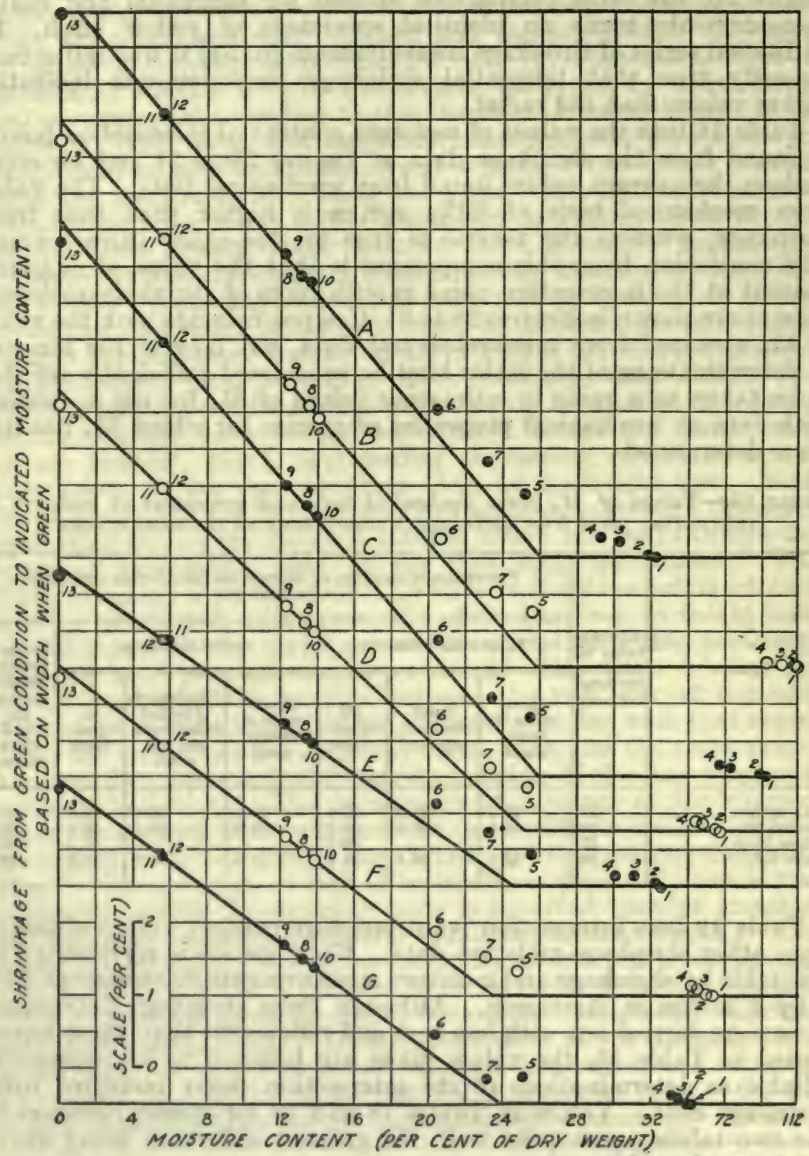

FIGURE 28.—Sitka spruce: Results of skrinkage measurements on specimens 1 by 4 by 1 inches: *A*, Tangential shrinkage based on 7 heartwood specimens; *B*, tangential shrinkage based on 11 sapwood specimens; *C*, tangential shrinkage, *A* and *B* combined; *E*, radial shrinkage based on 7 heartwood specimens *F*, radial shrinkage based on 11 specimens of mixed heartwood and sapwood averaging about 30 per cent sapwood; *G*, radial shrinkage, *E* and *F* combined; *D*, *C*, and *G* combined. Points are numbered in the order in which measurements were taken

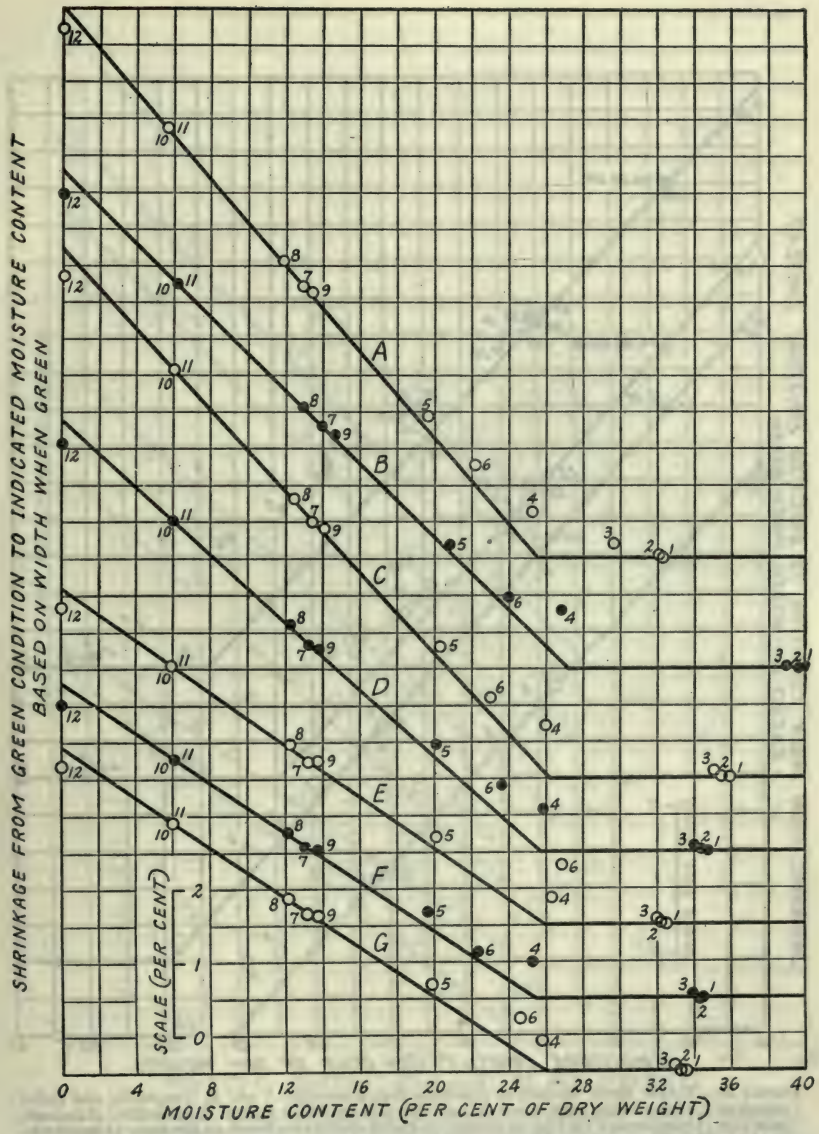

FIGURE 29.—Douglas fir: Results of shrinkage measurements on specimens 1 by 4 by 1 inches: *A*, Tangential shrinkage based on 10 heartwood specimens; *B*, tangential shrinkage based on 10 sapwood specimens; *C*, tangential shrinkage, *A* and *B* combined; *E*, radial shrinkage based on 10 heartwood specimens; *F*, radial shrinkage based on 9 specimens of mixed heartwood and sapwood averaging about 50 per cent sapwood; *G*, radial shrinkage, *E* and *F* combined; *D*, *C*, and *G* combined. Points are numbered in the order in which measurements were taken

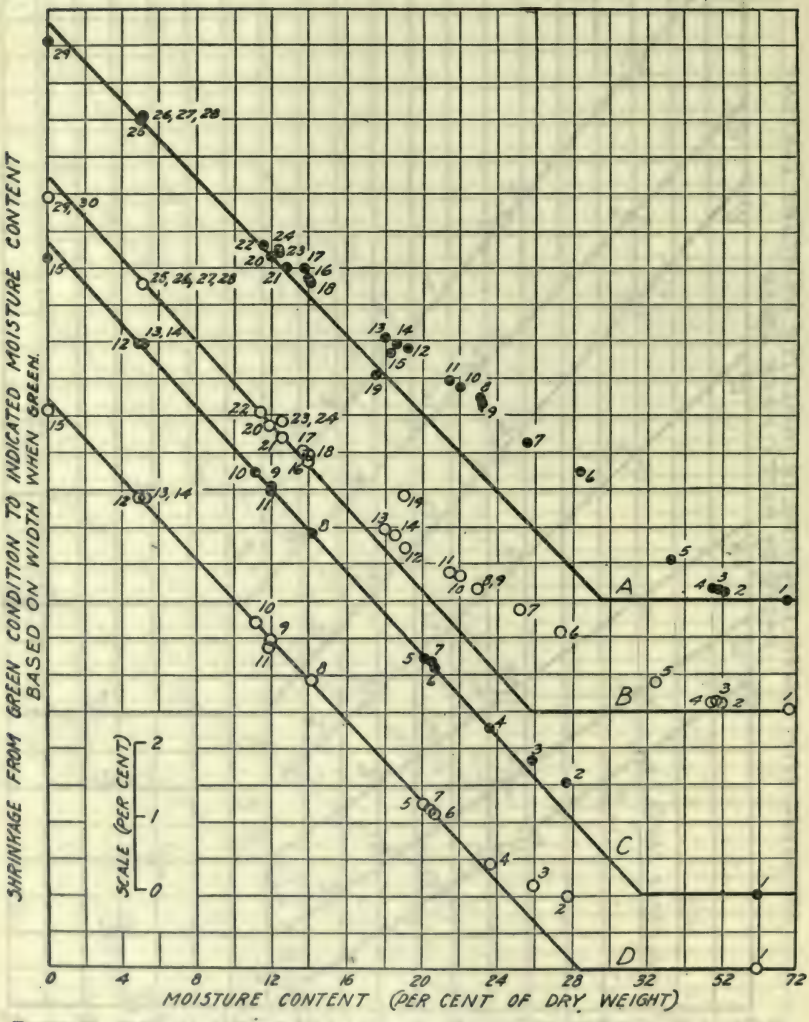

FIGURE 30.—Yellow birch: Results of shrinkage measurements: *A* and *B*, Tangential and radial shrinkages, respectively, each based on 5 specimens 1 by 4 by 1 inches; *C*, tangential shrinkage, based on 12 specimens 2 by 2 by ¼ inches; *D*, radial shrinkage, based on the same 12 specimens as at *C*. Points are numbered in the order in which measurements were taken

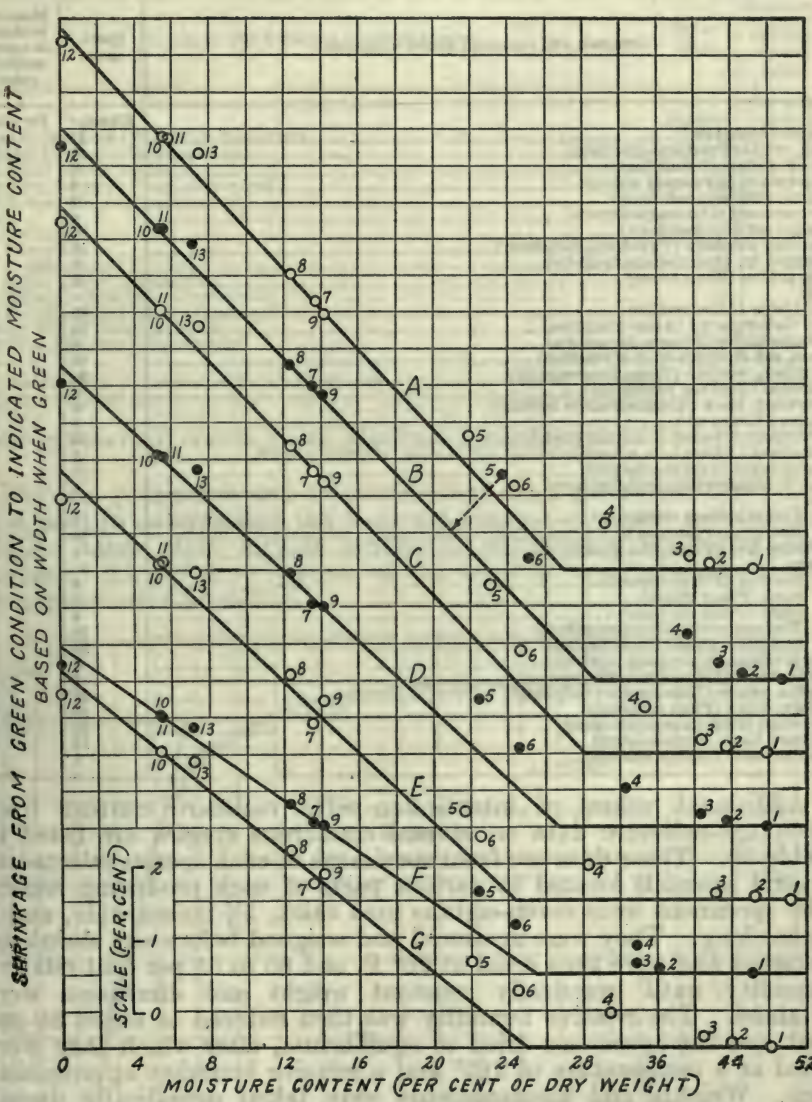

FIGURE 31.—White ash: Results of shrinkage measurements on specimens 1 by 4 by 1 inches: *A*, Tangential shrinkage based on 6 heartwood specimens; *B*, tangential shrinkage based on 6 sapwood specimens; *C*, tangential shrinkage, *A* and *B* combined; *E*, radial shrinkage based on 6 heartwood specimens; *F*, radial shrinkage based on 6 specimens of mixed heartwood and sapwood averaging about 50 per cent sapwood; *G*, radial shrinkage, *E* and *F* combined; *D*, *C*, and *G* combined. Points are numbered in the order in which measurements were taken

TABLE 19.—*Per cent moisture at intersection point as found from shrinkage measurements on specimens 1 by 4 by 1 inches*

(Averages of values found from radial and tangential shrinkages)

Common and botanical names of species	Specimens	Moisture content at intersection point
	Number	*Per cent*
Apple (Malus sp.)	31	32
Ash, white (Fraxinus americana)	23	25
Birch, yellow (Betula lutea)	9	29
Blackwood (Avicennia nitida)	4	24
Bustic (Dipholis salicifolia)	2	25
Buttonwood (Conocarpus erecta)	4	28
Cedar, red (Juniperus sp.)	4	28
Cypress, southern (Taxodium distichum)	16	27
Douglas fir, (Pseudotsuga taxifolia)	16	26
Fig, golden (Ficus aurea)	2	25
Fir:		
Noble (Abies nobilis)	16	27
California red (Abies magnifica)	12	24
Gumbo limbo (Bursera simarouba)	4	25
Gum, red (Liquidambar styraciflua)	18	32
Hemlock, western (Tsuga heterophylla)	24	23
Inkwood (Exothea paniculata)	4	32
Ironwood, black (Krugiodendron ferreum)	4	26
Khaya (Khaya sp.)	8	26
Mahogany, Central American (Swietenia sp.)	10	21
Mangrove (Rhizophora mangle)	4	25
Maple sugar (Acer saccharum)	12	28
Mastic (Sideroxylon foetidissimum)	4	22
Oak:		
Live (Quercus virginiana)	3	24
Red group (Quercus sp.)	14	33
Paradise tree (Simarouba glauca)	4	27
Pine:		
Norway (Pinus resinosa)	4	24
Sand (Pinus clausa)	4	26
Slash (Pinus caribaea)	4	25
Western white (Pinus monticola)	24	20
Northern white (Pinus strobus)	24	22
Plum, pigeon (Coccolobis laurifolia)	4	27
Poisonwood (Metopium toxiferum)	2	28
Poplar, yellow (Liriodendron tulipifera)	28	27
Spruce, Sitka (Picea sitchensis)	26	25
Redwood (Sequoia sempervirens)	10	20
Walnut, black (Juglans nigra)	21	23
Stopper, red (Eugenia confusa)	2	25

Additional values of intersection-point moisture content from shrinkage-moisture data on several coniferous species are listed in Table 20. These data are from specimens of each species selected at several sawmills located in various parts of each producing region. The specimens were seven-eighths inch thick, 5½ inches wide, and 8 inches long. They were measured and weighed before any shrinkage occurred and were then dried at 90° F. and 60 to 65 per cent relative humidity until practically constant weight and dimension were attained. The relative humidity was then reduced to about 30 per cent and the specimens dried to equilibrium, after which they were dried at a temperature of 210° and a relative humidity approaching zero. Weights and measurements were taken periodically during each of the first two stages of the drying and at the end of each of the three stages. Although the work was not done with the specific object of determining the intersection point, study of the data has indicated that they afford reasonably reliable estimates of this point. Because of the larger number of specimens involved, the values given in Table 20 are probably more accurate as averages than are those of Table 19. It may be further noted, however, that there are no very great discrepancies among Tables 18, 19, and 20 with respect to species that are common to two or to all three tables.

TABLE 20.—*Percentage of moisture at intersection point as found from shrinkage measurements on specimens ⅞ by 5½ by 8 inches*

(Averages of values found from radial and tangential shrinkages)

Common and botanical names of species	Specimens	Moisture content at intersection point
	Number	*Per cent moisture*
Cypress, southern (Taxodium distichum)	104	25
Douglas fir (Pseudotsuga taxifolia)	202	23
Fir, white (Abies concolor)	24	22
Hemlock, western (Tsuga heterophylla)	138	24
Larch, western (Larix occidentalis)	38	25
Pine:		
Loblolly [1]	100	22
Longleaf [1]	100	21
Shortleaf [1]	100	22
Sugar (Pinus lambertiana)	44	23
Western white (Pinus monticola)	80	22
Western yellow (Pinus ponderosa)	108	24
Spruce, Sitka (Picea sitchensis)	146	24
Redwood (Sequoia sempervirens)	146	21

[1] The grouping of southern yellow pine specimens into loblolly, longleaf, and shortleaf was done on the basis of the general appearance of the wood as no definite identification was possible.

FIBER-SATURATION POINTS FROM ELECTRICAL CONDUCTIVITY AND MOISTURE EQUILIBRIUM MEASUREMENTS

Physical properties and relations other than shrinkage that have been used in determining the moisture content at which a change of relation takes place include studies of electrical conductivity and studies of the moisture content of the wood in equilibrium with 100 per cent relative humidity.

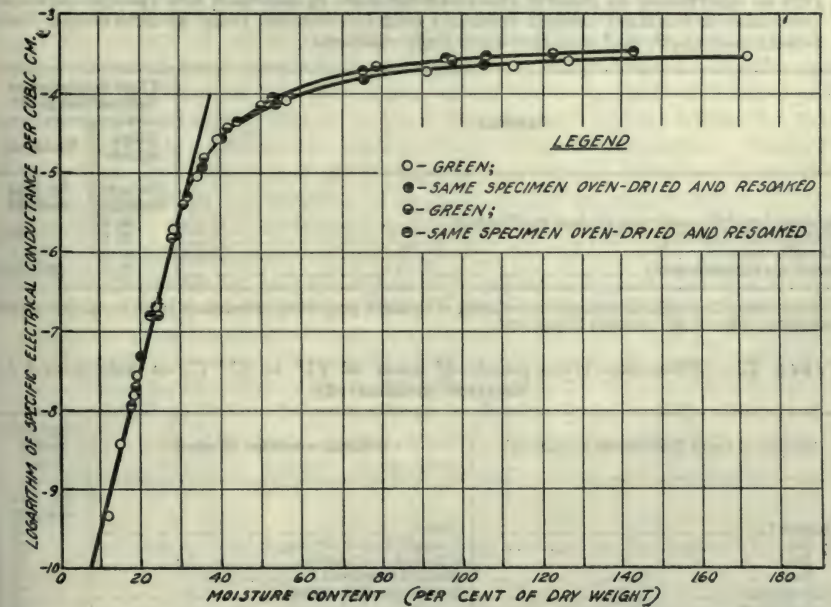

FIGURE 32.—Relation between the moisture content of redwood and its specific electrical conductance

Figure 32 exhibits the relation found between the moisture content of redwood and its specific electrical conductance (*10*). The point of

departure of the data from the straight-line relation shown for low values of moisture content is assumed to be the fiber-saturation point (about 29.5 per cent in this instance).

The moisture content of wood in equilibrium with 100 per cent relative humidity has never been accurately determined because of the tremendous effect of slight changes in temperature but from the extrapolation of data taken at lower relative humidities, the equilibrium moisture content at 100 per cent can be estimated as has been done for Sitka spruce in Figure 1. Values obtained in this way are found to agree quite closely with fiber-saturation points obtained from electrical-conductivity experiments. The available fiber-saturation-point values for different species as given by the equilibrium moisture-content and electrical-conductivity methods are included in Tables 21 and 22 and are seen to be consistently higher and to spread over a much smaller range than the intersection-point values indicated by data on shrinkage and mechanical properties. The greatest difference is in redwood, for which the electrical-conductivity method gives a value for the fiber-saturation point of about 30 per cent, whereas the intersection-point values obtained from two series of shrinkage measurements are, as shown by Tables 19 and 20, 20 and 21 per cent. Some recently available data on the relation of strength properties of redwood to its moisture content indicate a value of M_p of about 21 per cent. Also the electrical conductivity method gave 30½ per cent for Douglas fir, whereas the mechanical tests indicate a value of 24 per cent for M_p of this species.

TABLE 21.—*Fiber-saturation points of Sitka spruce and redwood at room temperature as determined by relative humidity-moisture equilibrium and specific electrical conductance-moisture content relations and intersection point as determined from moisture-strength and moisture-shrinkage relations*

Method	Fiber-saturation or intersection point	
	Sitka spruce	Redwood
	Per cent moisture	*Per cent moisture*
Relative humidity-moisture content equilibrium	30.5	----------
Electrical conductivity	29.0	29.5
Strength tests	27.0	(1)
Shrinkage measurements	25.3	20.0–21.0

[1] Some recently available data on the relation of strength properties of redwood to its moist urecontent indicate a value of M_p of about 21 per cent.

TABLE 22.—*Fiber-saturation points of wood at 24° to 27° C. as determined by electrical conductivity*

Species of wood (heartwood specimens)	Original condition of wood	Fiber-saturation point
		Per cent moisture
Redwood	Green	29.5
Do	Resoaked after drying	29.5
Do	Hot-water extracted	31.0
Do	Alcohol extracted	31.0
Sitka spruce	Resoaked after drying	29.0
Alaska cedar	----do	28.5
Western red cedar	----do	30.0
Western hemlock	----do	30.5
Western yellow pine	----do	30.0
California red fir	----do	30.0
Douglas fir	----do	30.5
Yellow poplar	----do	31.5

These comparisons suggest that the intersection points in such plots of moisture-strength and moisture-shrinkage data as are shown herein are not true fiber-saturation points of the respective species. However, it has been shown that a straight-line relation exists between percentage moisture, within a range somewhat below the intersection point or the fiber-saturation point, and the logarithm of the strength property. Failure of the intersection point to coincide with the true fiber-saturation point does not vitiate this relation nor render invalid its application in adjusting strength values for differences in moisture content.

SOME FURTHER CONSIDERATIONS PERTAINING TO STRENGTH-MOISTURE RELATIONS

Throughout the preceding discussion, the hypothesis that variations in moisture content have no effect on strength properties so long as the moisture content is above its fiber-saturation-point value has been tacitly accepted. The truth of this hypothesis, as far as the strength of the cell walls or other elements of the structure are concerned, follows from the definition of fiber-saturation point as stated on page 6. It has been suggested, however, that changes in moisture content above the fiber-saturation-point value may produce surface tension of the water in partially filled cell cavities sufficiently great to affect the strength properties of the wood.

Evidence exists that a different effect obtains when wood is thoroughly saturated and the cell cavities are completely filled with water. Deformation produced by the application of external forces may then cause sufficient hydraulic pressure within the cavities to stress and possibly disrupt the cell structure. No tests have been made with the specific object of studying this effect. Evidence that it operates to weaken wood with respect to strength in compression at right angles to grain is afforded by the observation that in static-bending tests more severe crushing occurs at load and support points when the wood has a very high moisture content than when its moisture content is lower but above the fiber-saturation-point value. Similar effects have been observed in the testing of wood heavily impregnated with creosote. Observation that buckling failures in the steam bending of wood are more common when the moisture content is very great affords further evidence of the action of hydraulic pressure within the cell cavities. Since, as is indicated by Figure 1, the fiber-saturation-point moisture content decreases as the temperature increases, the heating of the wood to near the boiling-point temperature, as is ordinarily done in steam bending, may cause some of the water that is "imbibed" or "bound" at lower temperatures to be released and to be added to the previously existing "free" water within the cavities. Also the bending operation causes comparatively large deformations; frequently as much as 10 or 12 per cent and in extreme cases as much as 25 per cent or more. Consequently, hydraulic pressure may be set up within the cell cavities even when these cavities are not filled with water at the beginning of the operation.

Increase in the strength of wood with decrease in moisture content may be considered to be the resultant of two factors: (1) Actual strengthening and stiffening of the elements of the wood structure; (2) increase in the compactness of the wood structure because of the shrinkage that accompanies loss of moisture. The effects of these two

factors are combined in the data considered herein. No satisfactory method of separating these effects has been found.

Experiments have indicated that the specific gravity of wood substance, that is, the material of which the cell walls are composed, varies but little among several species of wood (*3*, *9*). Consequently, differences in specific gravity of wood substance would be expected to have but little effect on the amount of moisture at the fiber-saturation point and would probably have no effect on the percentage of moisture at that point or on the increase in strength brought about by loss of moisture. Furthermore, as far as is known, the differences among species with respect to chemical composition are apparently not sufficient to account for any very wide variations in percentage of moisture at the fiber-saturation point or in the increase in strength produced in drying.

The data of Tables 21 and 22 indicate that there are no wide variations in fiber-saturation-point moisture content as determined by electrical-conductivity and moisture-equilibrium methods. Discrepancies between fiber-saturation-point values as determined by these two methods and the intersection-point values from strength tests are possibly due to the effect of the size and arrangement of elements of the wood structure on the intersection point. An indication of a relation between structure and intersection-point moisture content has been discussed on page 46. Table 23, which is based on data from Table 17, affords an indication of relation between the structure of the wood and the computed ratio of strength at zero moisture content to strength in the green condition. The species are arranged in order of decreasing ratio for maximum crushing strength, which it will be noted is closely paralleled by the ratio for modulus of rupture. Yellow birch, a diffuse porous hardwood heads the list. Next come five coniferous species, followed by two ring-porous hardwoods. Greenheart, an exotic species of very high specific gravity, is last. Except for red spruce, there is but little variation among the coniferous species with respect to the ratios listed, in spite of the fact that longleaf pine, loblolly pine, and Douglas fir, which have very distinct summer wood, and Sitka spruce, which has much less distinct summer wood, are included. In general, it may be said that there are distinct differences among the species as grouped in Table 23 with respect to the ratios shown in the last two columns.

TABLE 23.—*Computed ratios of strength at zero moisture content to strength in the green conditions*

Species	Ratio of strength at zero moisture content to strength in the green condition	
	Maximum crushing strength	Modulus of rupture
Group I: Yellow birch	5.20	3.45
Group II:		
Red spruce	4.19	
Longleaf pine	3.47	2.77
Douglas fir	3.47	2.70
Sitka spruce	3.47	2.49
Loblolly pine	3.31	
Group III:		
Chestnut	3.26	2.08
White ash	3.16	2.14
Group IV: Greenheart	1.99	

VARIABILITY OF K AND TABLE OF ADDITIONAL VALUES

Inspection of Table 17 suggests that K is less variable than the strength values. For example, considering data from compression-parallel-to-grain tests on individual trees of Douglas fir, the highest and lowest values of maximum crushing strength of green material are 4,150 and 3,330 pounds per square inch, respectively, giving a ratio of highest to lowest of 1.25 to 1, whereas highest and lowest values of K for this property are 0.0238 and 0.0211, giving a ratio of 1.13 to 1. Also consideration of the values of maximum crushing strength and corresponding values of K among the several species represented in Table 17 shows that the tabulated values of K are considerably less variable than the strength property. It is quite probable that among averages for different species, the value of K for any strength property is less variable than the strength property itself. Other data indicate, however, that a similar situation may not obtain with respect to different lots of material of the same species. At any rate, it has been found that strength properties of a species vary over a considerable range, their values being different in different trees and in different parts of the same trees. Accordingly, it is to be expected that the value of K for any property of any species will likewise be subject to variation, and consequently, in attempting to set up average values of K, it is desirable that all available data be considered.

Figure 17, in which moisture-strength data are presented for different specific-gravity classes of wood of the same species, affords little indication of correlation between specific gravity and K. Values of K as found from the data of this figure are given in Table 9.

A similar study shows (1) that approximately the same value of K applies to the three higher specific-gravity classes of Douglas fir, whereas that for the lowest specific-gravity class of this species is distinctly lower and (2) that practically the same value of K applies to the four specific-gravity classes of yellow birch.

The Sitka spruce individual-tree values of specific gravity and of K for maximum crushing strength and for modulus of rupture as shown in Table 17 afford an indication that K increases as specific gravity decreases. Values given in the same table for Douglas fir and yellow birch indicate that K for modulus of rupture increases as the specific gravity increases, whereas no correlation between K for maximum crushing strength of Douglas fir and its specific gravity is indicated. In none of these instances, however, is the change in K with change in specific gravity consistent, and no close correlation is indicated.

Additional data for the determinations of values of K are afforded by results of a standard series of strength tests on American species that have been made at the Forest Products Laboratory (*6*, *7*). In this series tests were made on green and seasoned specimens from similar locations in the same trees. From these tests, values of K can be derived for those species for which M_p has been determined. Such values are listed in Table 24 for several properties of several species.

TABLE 24.—*Compilation of values of K*

Species	*Mp*	Weighting factor [1]	Specimens [2]	Moisture content of seasoned material	Values of *K*												
					Compression parallel to grain		Static bending					Impact bending			Compression perpendicular to grain (fiber stress at elastic limit)	Hardness		Shear (average of radial and tangential)
					Fiber stress at elastic limit	Maximum crushing strength	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Fiber stress at elastic limit	Work to elastic limit	Maximum drop		End	Side	
Ash:			*Number*	*Per cent*														
Biltmore white	[3] 24		71	5.4	-------	0.0223	0.0186	0.0122	0.0066	0.0297	0.0002	0.0118	0.0174	0.0102	0.0198	0.0185	0.0107	0.0113
Blue	[3] 24		48	9.6	-------	.0185	.0129	.0129	.0042	.0216	−.0009	.0180	.0219	−.0009	.0205	.0149	.0082	.0100
Green	[3] 24		53	11.2	-------	.0201	.0239	.0149	.0069	.0406	.0057	.0102	.0097	.0000	.0163	.0225	.0149	.0131
			43	9.6	-------	.0177	.0146	.0143	.0052	.0242	.0034	.0155	.0211	−.0059	.0241	.0164	.0089	.0169
White	24		27	10.5	-------	.0201	.0234	.0186	.0103	.0362	.0074	.0079	.0092	.0013	.0127	.0198	.0109	.0153
			26	9.5	-------	.0213	.0217	.0160	.0058	.0378	.0011	.0159	.0223	−.0006	.0276	.0189	.0121	.0127
			48	6.9	-------	.0232	.0187	.0167	.0069	.0304	−.0005	.0121	.0188	−.0005	.0233	.0189	.0113	.0130
			14	12.2	-------	.0264	.0170	.0186	.0076	.0270	−.0022	−.0218	−.0276	−.0030	.0167	.0222	.0117	.0063
			10	11.6	-------	.0219	.0174	.0163	.0046	.0294	.0046	.0121	.0173	.0240	.0181	.0173	.0097	.0142
		5	-------	-------	-------	.0208	.0148	.0138	.0066	.0206	−.0057	-------	-------	−.0026	.0238	-------	-------	.0155
Average	------	-------	-------	-------	-------	.0217	.0172	.0155	.0068	.0264	−.0018	.0052	.0080	.0008	.0217	.0194	.0111	.0139
Average [3] (biltmore white, blue, green, and white)	------	-------	-------	-------	-------	.0211	.0173	.0150	.0065	.0271	−.0007	.0091	.0122	.0008	.0213	.0188	.0109	.0136
Birch, yellow	27	-------	34	10.3	0.0273	.0268	.0303	.0219	.0106	.0496	.0060	.0131	.0199	.0100	.0293	.0158	.0136	.0054
		-------	43	9.0	.0242	.0250	.0202	.0180	.0074	.0322	.0043	.0167	.0201	.0087	.0273	.0175	.0150	.0179
		-------	24	11.1	.0181	.0250	.0308	.0216	.0063	.0526	.0198	.0079	.0068	−.0032	.0164	.0204	.0129	.0171
		-------	22	11.1	-------	.0250	.0241	.0194	.0051	.0420	.0003	.0061	.0060	−.0020	.0141	.0209	.0181	.0193
		-------	8	11.2	.0256	.0245	.0248	.0185	.0073	.0421	.0067	.0028	−.0040	−.0037	.0190	.0135	.0071	.0196
		-------	29	11.3	.0243	.0270	.0243	.0252	.0143	.0338	.0146	.0084	.0036	.0005	.0176	.0198	.0150	.0244
		-------	16	11.1	.0237	.0223	.0232	.0174	.0032	.0427	.0081	.0035	.0005	−.0032	.0219	.0170	.0132	.0159
		8	-------	-------	-------	.0265	.0194	.0199	.0045	-------	.0065	-------	-------	.0015	.0216	-------	-------	.0131
Average	------	-------	-------	-------	.0239	.0258	.0222	.0201	.0060	.0421	.0075	.0084	.0076	.0013	.0212	.0178	.0136	.0150
Chestnut	24	-------	7	7.4	.0247	.0234	.0226	.0173	.0109	.0343	−.0031	-------	-------	-------	.0217	-------	-------	.0159
		-------	8	8.0	.0236	.0232	.0260	.0199	.0090	.0427	.0067	.0098	.0170	.0000	.0268	.0155	.0127	.0077
		-------	8	9.2	.0296	.0223	.0219	.0133	.0121	.0319	−.0176	.0089	.0087	−.0131	.0232	.0128	.0052	.0101
		-------	7	10.1	.0220	.0253	.0193	.0166	.0154	.0195	−.0072	.0153	.0210	−.0019	-------	-------	-------	.0096

			52	9.0	.0252	.0309	.0259	.0184	.0097	.0415	−.0023	.0168	.0283	−.0104	.0279	.0179	.0108	.0155
			77	8.3	.0213	.0290	.0253	.0146	.0091	.0416	−.0031	.0063	.0102	−.0026	.0170	.0075	.0062	.0123
			21	9.4	.0149	.0237	.0206	.0139	.0090	.0314	−.0005	.0139	.0228	−.0047	.0242	.0055	.0073	.0067
			22	8.2	.0233	.0275	.0287	.0160	.0085	.0488	−.0048	.0066	.0196	−.0098	.0247	.0117	.0098	.0101
			24	8.4	.0189	.0255	.0287	.0144	.0105	.0446	−.0056	.0102	.0134	−.0030	.0302	.0107	.0097	.0074
			23	8.9	.0209	.0278	.0211	.0139	.0132	.0304	−.0070	.0102	.0168	−.0060	.0310	.0093	.0097	.0079
			22	8.1	.0290	.0257	.0271	.0152	.0139	.0403	.0005	.0076	.0111	−.0185	.0260	.0065	.0091	.0096
			21	8.6	.0274	.0290	.0263	.0194	.0109	.0408	.0019	.0129	.0154	.0000	.0251	.0076	.0080	.0131
			22	9.9	.0275	.0280	.0246	.0177	.0082	.0417	.0006	.0046	.0035	−.0023	.0158	.0049	.0062	.0112
			23	9.2	.0252	.0271	.0194	.0104	.0088	.0311	.0009	.0090	.0129	.0025	.0232	.0155	.0102	.0096
			24	10.2	.0161	.0261	.0243	.0157	.0088	.0409	−.0022	.0131	.0242	.0038	.0228	.0127	.0082	.0074
			23	8.0	.0272	.0287	.0296	.0205	.0118	.0476	.0013	.0073	.0157	−.0182	.0310	.0167	.0127	.0101
		10				.0214	.0187	.0132	.0068									
		5				.0218												
Average					.0236	.0241	.0222	.0150	.0091	.0381	−.0025	.0102	.0160	−.0052	.0247	.0111	.0090	.0103
Douglas fir	24		82	6.5		.0256	.0218	.0181	.0086	.0348	.0112	.0132	.0205	.0123	.0268	.0173	.0131	.0095
			38	6.8		.0282	.0197	.0163	.0110	.0286	.0047	.0117	.0160	.0057	.0053	.0133	.0158	.0096
			80	6.0		.0246	.0215	.0168	.0066	.0366	.0071	.0126	.0161	.0102	.0204	.0121	.0098	.0085
			70	5.9		.0228	.0195	.0153	.0063	.0326	.0061	.0125	.0218	.0110	.0230	.0125	.0098	.0059
			79	6.8		.0248	.0215	.0170	.0070	.0362	.0123	.0087	.0101	.0126	.0137	.0133	.0110	.0091
			105	11.6		.0230	.0208	.0182	.0055	.0353	.0144	.0125	.0154	.0120	.0273	.0096	.0091	.0142
			81	11.4		.0241	.0232	.0193	.0065	.0384	.0178	.0072	.0086	.0049	.0298	.0137	.0100	.0145
			72	11.1		.0188	.0155	.0174	.0057	.0251	.0128	.0072	.0092	.0000	.0240	.0108	.0082	.0071
			27	12.1		.0208	.0145	.0166	.0090	.0182	.0105	.0046	.0000	.0078	.0284	.0176	.0159	−.0052
			55	11.4		.0207	.0209	.0200	.0063	.0326	.0186	.0138	.0090	.0087	.0384	.0234	.0127	.0000
			55	12.2		.0164	.0194	.0171	.0059	.0320	.0098	.0052	−.0084	.0068	.0260	.0184	.0125	.0021
			25	11.8		.0135	.0119	.0155	.0051	.0190	.0102	.0007	−.0069	−.0004	.0147	.0151	.0099	−.0004
			59	6.2		.0246	.0189	.0167	.0075	.0304	.0143	.0095	.0167	.0079	.0231	.0129	.0090	.0096
		5				.0225	.0200	.0160	.0063	.0326	.0058			.0062	.0234			.0091
			44	9.8		.0259	.0282	.0197	.0045	.0518	.0080	.0082	.0156	.0055	.0223	.0137	.0133	.0133
			41	9.3		.0256	.0238	.0190	.0079	.0395	.0160	.0091	.0124	.0117	.0169	.0095	.0120	.0112
			40	9.9		.0281	.0224	.0198	.0067	.0382	.0142	.0108	.0160	.0073	.0310	.0103	.0105	.0152
			39	9.9		.0263	.0270	.0205	.0070	.0462	.0082	.0137	.0220	.0050	.0162	.0158	.0119	.0098
			40	9.9		.0248	.0247	.0160	.0059	.0429	.0006	.0136	.0206	.0062	.0224	.0096	.0075	.0074
			49	9.9		.0255	.0279	.0156	.0065	.0485	−.0026	.0095	.0121	.0066	.0259	.0101	.0083	.0096
			43	9.6		.0276	.0277	.0214	.0084	.0465	.0104	.0114	.0205	.0112	.0248	.0112	.0125	.0121
			19	12.9		.0265	.0198	.0150	.0081	.0328	−.0040				.0219	.0210	.0144	.0184
			50	6.8		.0244	.0188	.0144	.0079	.0280	.0007	.0118	.0198	.0088	.0223	.0120	.0142	.0021
Average						.0235	.0211	.0172	.0069	.0347	.0085	.0099	.0127	.0074	.0230	.0138	.0114	.0085

[1] Numerals in this column are on lines giving values of K derived from data presented in Figures 8 to 25 and indicate the number of trees or series of specimens. Each such line of values was weighted according to this number in averaging. Each other line of values is based on tests from a single tree and was given unit weight in averaging.

[2] Number of specimens in each of the two conditions, green and seasoned, on which determinations of maximum crushing strength were made. The number of static bending specimens is about one-half and that for fiber stress at elastic limit, compression perpendicular to grain, end hardness, and side hardness each one-fourth as great. The number of impact bending and shear specimens varies, being usually at least four for impact bending and three each for radial and tangential shear.

[3] As Biltmore white, blue, green, and white ashes are very similar botanically and in many strength properties, the value of Mp determined from tests of white ash has been assumed to apply to each of the other three species, and values of K have been combined to form averages for this group of species.

TABLE 24.—*Compilation of values of K*—Continued

Species	*Mp*	Weighting factor	Specimens	Moisture content of seasoned material	Values of *K*													
					Compression parallel to grain		Static bending					Impact bending			Compression perpendicular to grain (fiber stress at elastic limit)	Hardness		Shear (average of radial and tangential)
					Fiber stress at elastic limit	Maximum crushing strength	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Fiber stress at elastic limit	Work to elastic limit	Maximum drop		End	Side	
			Number	*Per cent*														
Pine, loblolly	21		31	7.1	0.0360	0.0351	0.0314	0.0237	0.0088	0.0530	0.0091	0.0197	0.0290	0.0022	0.0337	0.0322	0.0189	0.0215
			41	7.8	.0336	.0360	.0314	.0239	.0125	.0486	.0057	.0124	.0175	−.0134	.0373	.0293	.0190	.0210
			23	5.5	.0241	.0325	.0280	.0224	.0166	.0391	−.0009	.0101	.0151	−.0135	.0326	.0302	.0202	.0167
			23	5.7	.0292	.0323	.0256	.0205	.0113	.0398	.0025	.0124	.0162	−.0027	.0296	.0235	.0167	.0178
			24	11.2	.0335	.0362	.0320	.0299	.0095	.0542	.0164	.0168	.0206	−.0087	.0289	.0204	.0201	.0195
			24	11.4	.0365	.0331	.0397	.0267	.0077	.0718	.0099	.0165	.0168	.0039	.0271	.0292	.0306	.0241
			19	11.5	.0173	.0383	.0316	.0259	.0107	.0519	.0068	.0202	.0224	.0078	.0297	.0210	.0288	.0190
			22	11.3	.0232	.0342	.0351	.0298	.0113	.0564	.0170	.0221	.0243	.0033	.0324	.0205	.0248	.0146
			24	11.1	.0461	.0339	.0371	.0287	.0092	.0634	.0096	.0221	.0298	.0055	.0321	.0259	.0261	.0217
			29	11.2	.0373	.0352	.0377	.0300	.0136	.0595	.0126	.0203	.0235	.0058	.0346	.0358	.0181	.0201
			19	11.2	.0351	.0333	.0322	.0264	.0152	.0479	.0035	.0109	.0091	−.0012	.0511	.0234	.0188	.0238
			24	11.1	.0416	.0351	.0357	.0296	.0089	.0632	.0169	.0191	.0216	.0116	.0280	.0312	.0176	.0229
			18	11.0	.0223	.0289	.0383	.0310	.0185	.0562	.0111	.0126	.0133	.0048	.0292	.0132	.0069	.0179
			24	10.7	.0142	.0315	.0315	.0259	.0135	.0590	.0169	.0077	−.0026	.0200	.0356	.0196	.0116	.0145
			33	11.9	.0233	.0355	.0413	.0307	.0144	.0681	.0144	.0156	.0130	.0073	.0528	.0331	.0232	.0230
			26	12.2	.0334	.0378	.0384	.0322	.0125	.0566	.0193	.0236	.0347	.0000	.0422	.0250	.0250	.0219
			29	11.8	.0415	.0375	.0359	.0310	.0138	.0578	.0207	.0154	.0174	.0009	.0424	.0344	.0231	.0256
			28	12.0	.0291	.0370	.0317	.0257	.0100	.0530	.0100	.0152	.0118	−.0005	.0417	.0357	.0239	.0185
			24	12.2	.0572	.0326	.0311	.0220	.0138	.0458	−.0026	.0144	.0109	−.0053	.0607	.0365	.0170	.0174
			25	12.1	.0328	.0337	.0423	.0272	.0095	.0736	.0114	.0135	.0083	.0029	.0479	.0239	.0185	.0168
			24	12.0	.0358	.0338	.0419	.0282	.0082	.0738	.0060	.0194	.0200	.0015	.0521	.0272	.0199	.0242
			30	12.5	.0259	.0339	.0421	.0314	.0097	.0728	.0175	.0123	.0107	.0103	.0298	.0265	.0302	.0164
			28	12.2	.0347	.0327	.0405	.0278	.0067	.0710	.0080	.0163	.0188	−.0005	.0365	.0333	.0223	.0182
			38	12.3	.0310	.0339	.0454	.0310	.0096	.0806	.0163	.0189	.0220	−.0032	.0512	.0342	.0268	.0137
			34	13.2	.0268	.0413	.0235	.0307	.0167	.0300	.0137	.0150	.0137	−.0023	.0176	.0221	.0233	.0255
			32	12.7	.0398	.0361	.0186	.0266	.0130	.0238	.0094	.0020	−.0033	.0050	.0022	.0183	.0190	.0200
			38	12.0	.0309	.0334	.0313	.0286	.0148	.0480	.0166	.0152	.0141	−.0056	.0110	.0256	.0232	.0218
			38	12.2	.0284	.0371	.0316	.0293	.0133	.0493	.0208	.0176	.0176	.0035	.0120	.0271	.0274	.0252
			40	12.1	.0200	.0326	.0277	.0296	.0153	.0395	.0112	.0111	.0054	−.0016	.0345	.0235	.0168	.0239
			31	12.0	.0239	.0297	.0278	.0286	.0182	.0380	.0139	.0150	.0134	−.0037	.0259	.0224	.0169	.0229
		5				.0247												
Average					.0315	.0331	.0359	.0278	.0122	.0549	.0114	.0156	.0162	.0011	.0341	.0268	.0212	.0203

Pine, longleaf	21		54	12.0	.0270	.0309	.0317	.0236	.0093	.0534	.0199	.0221	.0349	−.0056	.0505	.0220	.0205	.0235
			44	7.4	.0255	.0338	.0279	.0221	.0115	.0441	.0117	.0143	.0196	−.0025	.0316	.0298	.0212	.0112
			41	6.2	.0215	.0313	.0276	.0227	.0119	.0431	.0115	.0185	.0284	.0009	.0341	.0293	.0219	.0163
			37	6.7	.0294	.0321	.0281	.0254	.0123	.0439	.0150	.0156	.0210	.0038	.0423	.0257	.0196	.0225
			37	7.4	.0304	.0356	.0280	.0244	.0136	.0427	.0162	.0179	.0244	.0000	.0400	.0262	.0238	.0168
			28	6.8	.0321	.0341	.0290	.0231	.0128	.0450	.0072	.0105	.0166	−.0045	.0277	.0221	.0137	.0139
			26	7.6	.0311	.0319	.0287	.0224	.0097	.0477	.0104	.0099	.0142	−.0015	.0248	.0198	.0118	.0061
			24	12.8	.0159	.0307	.0227	.0298	.0193	.0241	.0189	.0436	.0741	.0078	.0118	.0208	.0223	.0182
			24	12.7	.0091	.0329	.0284	.0316	.0128	.0438	.0238	.0334	.0525	.0016	.0383	.0117	.0227	.0167
			14	12.7	.0424	.0307	.0248	.0283	.0144	.0347	.0144	.0181	.0193	.0136		.0146	.0163	.0110
			15	12.5	.0234	.0321	.0223	.0258	.0077	.0373	.0136	.0136	.0058	−.0115	.0458	.0189	.0242	.0269
			8	13.0	.0411	.0352	.0339	.0282	.0061	.0596	.0117	.0373	.0639	.0131	.0585	.0178	.0143	.0248
			20	14.0	.0385	.0357	.0313	.0278	.0115	.0510	.0144	.0289	.0434	.0048	.0394	.0230	.0255	.0288
			16	13.8	.0228	.0345	.0358	.0312	.0117	.0592	.0172	.0268	.0392	−.0062	.0572	.0297	.0191	.0236
			8	13.1	.0362	.0299	.0167	.0270	.0130	.0202	.0163	.0342	.0586	−.0087	.0296			.0255
			24	13.9	.0295	.0341	.0265	.0300	.0118	.0412	.0233	.0330	.0552	.0084	.0275	.0247	.0228	.0136
			28	13.5	.0350	.0315	.0189	.0279	.0131	.0234	.0126	.0307	.0491	−.0048	.0176	.0245	.0196	.0183
			26	11.0	.0318	.0318	.0283	.0308	.0308	.0455	.0265	.0248	.0365	.0004	.0238	.0183	.0209	.0264
			24	11.1	.0431	.0315	.0271	.0270	.0125	.0410	−.0027	.0253	.0369	−.0053	.0085	.0287	.0205	.0290
			23	12.9	.0309	.0338	.0274	.0258	.0081	.0465	.0005	.0226	.0344	−.0172	.0254	.0210	.0161	.0283
			23	12.3	.0318	.0355	.0376	.0320	.0157	.0588	.0154	.0276	.0439	−.0015	.0303	.0259	.0249	.0324
			23	12.3	.0467	.0362	.0348	.0326	.0117	.0569	.0250	.0239	.0390	.0009	.0516	.0253	.0231	.0250
			22	11.8	.0234	.0302	.0250	.0287	.0087	.0382	.0271	.0268	.0412	−.0042	.0297	.0261	.0214	.0292
			11	12.6	.0326	.0337	.0215	.0265	.0043	.0394	.0109	.0225	.0367	.0039	.0425	.0175	.0094	.0243
			16	11.4	.0355	.0339	.0234	.0294	.0122	.0336	.0234	.0272	.0327	.0049	.0294	.0178	.0155	.0288
			8	11.4	.0311	.0337	.0217	.0180	.0024	.0411	−.0127	.0236	.0286	.0024	.0446	.0152	.0082	.0233
			14	11.2	.0365	.0323	.0253	.0262	.0120	.0383	.0174	.0274	.0368	−.0021	.0233	.0340	.0218	.0141
		6				.0257	.0245	.0210	.0062	.0396								.0157
		5				.0207												
Average					.0309	.0302	.0267	.0259	.0103	.0422	.0144	.0244	.0366	−.0003	.0341	.0227	.0193	.0204
Spruce, Sitka	27		116	8.9		.0192	.0208	.0171	.0073	.0334	−.0115	.0133	.0175	−.0031	.0266	.0087	.0098	.0098
			281	12.7		.0228	.0238	.0167	.0087	.0257	.0118	.0073	.0055	.0019	.0317	.0193	.0146	.0174
			115	12.2		.0235	.0180	.0152	.0053	.0291	.0108	.0090	.0092	.0047	.0232	.0175	.0113	.0173
			161	12.6		.0217	.0200	.0155	.0062	.0389	.0079	.0041	.0030	.0033	.0305	.0239	.0140	.0179
			183	13.1		.0210	.0170	.0162	.0067	.0271	.0070	.0083	.0085	−.0019	.0247	.0185	.0130	.0168
			23	11.3		.0256	.0232	.0216	.0128	.0339	.0132	.0088	.0071	−.0030	.0125	.0136	.0122	.0126
			34	11.3		.0236	.0177	.0173	.0080	.0267	.0105	.0070	.0048	−.0008	.0162	.0147	.0140	.0094
			144	10.0		.0205	.0205	.0165	.0059	.0346	.0095	.0057	.0035	.0097	.0176	.0140	.0068	.0098
			120	10.0		.0228	.0224	.0182	.0058	.0380	.0151	.0058	.0032	.0043	.0204	.0273	.0156	.0084
		5				.0200	.0161	.0147	.0060	.0260	.0099			.0027	.0187			.0072
Average						.0215	.0188	.0163	.0069	.0298	.0105	.0077	.0069	.0020	.0212	.0175	.0124	.0111
Spruce, red	27		57	7.5		.0237	.0209	.0163	.0058	.0357	.0078	.0175	.0248	.0112	.0163	.0126	.0095	.0102
			40	8.0		.0230	.0194	.0158	.0042	.0333	.0062	.0118	.0161	.0066	.0149	.0073	.0086	.0041
		5				.0234												
		11				.0229												
		5				.0217												
Average						.0228	.0202	.0160	.0050	.0345	.0070	.0146	.0204	.0089	.0156	.0100	.0090	.0072

The method of computing the values of K listed in Table 24 will be evident from examples presented later. (Examples 1–A and 1–B, p. 69.) The computed values are shown in detail rather than by averages alone in order to afford further information on the variability of K. It appears from inspection that K for any one species and property varies through a considerable range. Two causes of the variation exhibited are: (1) K actually varies for different trees and different lots of material; (2) specimens tested in the seasoned condition did not exactly match the green specimens. It is impossible to determine how much of the variation in computed values is due to each of these causes. In Table 24 the kinds of tests are arranged approximately in the order of the number of specimens. The largest number of specimens were tested in compression parallel to grain, about one-half as many in static bending, about one-fourth as many in compression perpendicular to grain and hardness, and, on an average, a yet smaller number in impact bending and shear. Inspection indicates that the tabulated values of K are less variable for those properties represented by the larger number of tests and that the variability increases as the number of tests decreases. This suggests that if green and seasoned specimens were in all cases perfectly matched the variability in values of K would be considerably reduced. The lack of perfect matching is a compensating factor probably causing the values to be too high as often as too low so that its effect on average values is probably quite small.

USE OF THE EXPONENTIAL FORMULA IN THE ADJUSTMENT OF STRENGTH VALUES

The following methods of adjusting strength values for differences in moisture content are based on the exponential formula which implies a straight-line relation between the percentage moisture content and the logarithm of the strength property. All problems of adjustment are covered by two cases as follows:

CASE 1.—Strength values derived from matched specimens tested at two different moisture-content values are known, and the value at some third moisture-content value is desired.

CASE 2.—The strength value at only one moisture-content value is known, and that at a second is desired.

Formulas for use in either of these cases can readily be derived from equations already given (9) and the adjusted values computed by the use of a slide rule or a table of logarithms. The computations, however, can be handled very easily by graphical methods on semilogarithmic paper [13] or specially prepared diagrams. The use of graphical methods and of the corresponding formulas can best be explained by examples under each case.

EXAMPLES OF CASE 1

EXAMPLE 1–A

United States Department of Agriculture Bulletin 556 (7) gives the maximum crushing strength of Sitka spruce in compression parallel

[13] Semilogarithmic paper has a series of vertical lines uniformly spaced and a series of horizontal lines spaced according to the logarithms of numbers.

to grain as 2,600 and 5,770 pounds per square inch in the green condition and at 8.9 per cent moisture, respectively. What would have been the maximum crushing strength if tests had been made at 12 per cent moisture? The solution is shown in the lower part of Figure 33, where 5,770 is plotted at 8.9 per cent moisture and 2,600 at 27 per cent, which as shown by Table 17, is the value of M_p for Sitka spruce. The line connecting these points crosses the vertical representing 12 per cent moisture at 5,020, which is the value of maximum crushing strength adjusted to 12 per cent.

This procedure is the graphical solution of the following formula:

$$\text{Log } S_3 = \log S_1 + \frac{M_1 - M_3}{M_1 - M_2} (\log S_2 - \log S_1) \qquad (10)$$

Where S_1 and M_1 are one pair of corresponding strength and moisture-

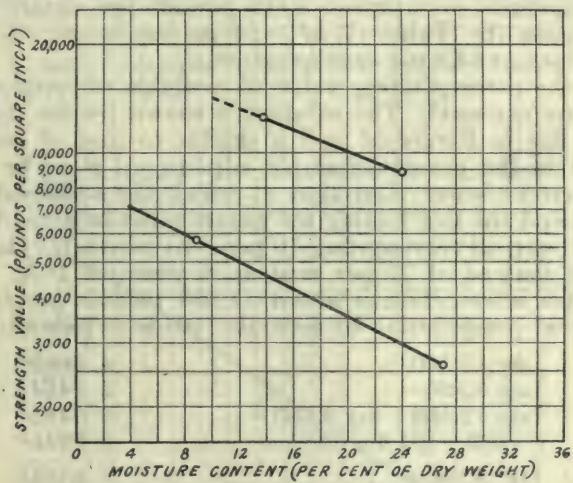

FIGURE 33.—Graphical solution of Examples 1-A and 1-B

content values as found from test, S_2 and M_2 are another pair, and S_3 is the strength value adjusted to moisture content M_3. In this example $S_1 = 2{,}600$, $M_1 = 27$, $S_2 = 5{,}770$, $M_2 = 8.9$, $M_3 = 12.0$, and the solution gives $S_3 = 5{,}030$ pounds per square inch.

Formula (10) is derived as follows. Equation 9 may by permutation of subscripts be written:

$$\text{Log } S_2 = \log S_p + K (M_p - M_2) \qquad (a)$$
$$\text{Log } S_1 = \log S_p + K (M_p - M_1) \qquad (b)$$
$$\text{Log } S_3 = \log S_1 + K (M_1 - M_3) \qquad (c)$$

Subtracting (b) from (a) and solving—

$$K = \frac{\log S_2 - \log S_1}{M_1 - M_2}$$

and equation (10) results when this value of K is substituted in (c). The numerical computation by formula (10) is as follows:

Log 5,770 =	3. 7612
Log 2,600 =	3. 4150
Log 5,770 − log 2,600 =	0. 3462
0.3462 ÷ (27.0 − 8.9)	0. 0191
Log 2,600 =	3. 4150
0.0191 × (27.0 − 12.0) =	0. 2865
Log 2,600 + 0.0191 × 15.0 =	3. 7015 = log 5030

and 5,030 pounds per square inch is the adjusted value, which does not differ significantly from the 5,020 read from the graph.

EXAMPLE 1–B

Tests of matched groups of white ash specimens gave the following values for modulus of rupture: 8,880 pounds per square inch in the green condition (by Table 17 $M_p = 24$ per cent) and 12,500 pounds per square inch at 13.8 per cent moisture.

What is the corresponding value of modulus of rupture at 10 per cent moisture content? The solution is shown by the upper pair of points and line in Figure 33 and is similar to that of example 1–A, except that in the present example adjustment is to be made to a moisture content lower than that at which the seasoned specimens were tested and the line joining the points must be extended in order to meet the vertical representing 10 per cent moisture; also the value of M_p is 24 instead of 27 per cent as in example 1–A. The value shown at this intersection is about 14,300 pounds per square inch. The numerical computation by formula (10) is as follows:

Log 12,500 =	4. 0969
Log 8,880 =	3. 9484
Log 12,500 − log 8,880 =	0. 1485
0.1485 ÷ (24.0 − 13.8) =	0. 0146
Log 8,880 =	3. 9484
0.0146 × (24.0 − 10.0) =	0. 2044
Log 8,880 + 0.0146 × 14.0 =	4. 1528 = log 14,220

and 14,220 pounds per square inch is the value adjusted to 10 per cent moisture content.

EXAMPLE OF CASE 2

EXAMPLE 2

A specimen of longleaf pine at 9.8 per cent moisture content was found from test to have a modulus of rupture of 13,500 pounds per square inch. What would have been the modulus of rupture if the test had been made at 12 per cent moisture? In this case no tests of matched green specimens are available, and in order to make the adjustment a value of K is required. The average value of K for modulus of rupture of longleaf pine of 0.0259 as given in Table 24 will be used. The graphical solution is as follows: 13,500 is plotted at 9.8 per cent moisture in Figure 34. The next step is to draw through this point a line whose inclination to the horizontal is equal to the value of K. Data for doing this is afforded by Figure 35, in which are shown for various values of K, values of Z, a multiplying

factor corresponding to a horizontal distance equal to 30 per cent on the scale of moisture content. For a value of K of 0.0259, the graph of Figure 35 gives a value of 6.0 for Z. Then in Figure 34, 1,000 is plotted at 30 per cent and 6,000, which is equal to six times 1,000, is plotted at 0 per cent moisture. The line connecting these two points has the desired inclination. A line is drawn parallel to this line and through the point first plotted in Figure 34. From this line the modulus of rupture adjusted to any moisture content below the intersection point can be read. The reading for 12 per cent moisture is about 11,800 pounds per square inch.

This procedure is a graphical solution of the following formula:

$$\text{Log } S_2 = \log S_1 - K\,(M_2 - M_1) \qquad (11)$$

Where S_1 and M_1 are the pair of corresponding strength and moisture content values as found from test and S_2 is the strength value adjusted

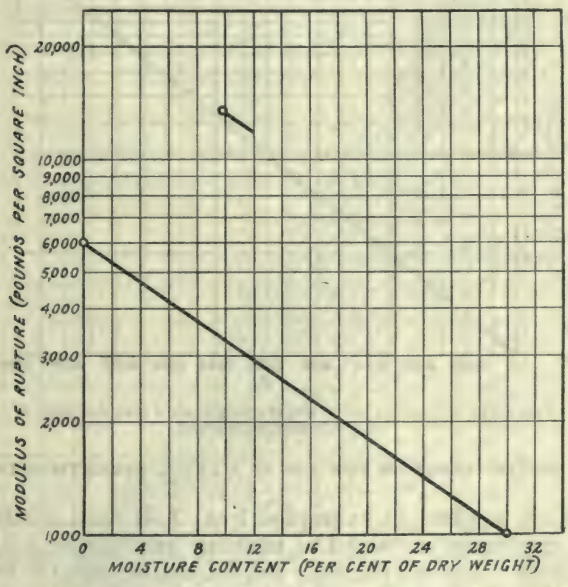

FIGURE 34.—Graphical solution of example 2

to the moisture content M_2. In this example, $S_1 = 13{,}500$, $M_1 = 9.8$, $M_2 = 12.0$, K was taken as 0.0259 and the graphical solution gives $S_2 = 11{,}830$ pounds per square inch. Formula (11) is obtained by changing subscripts and arrangement of terms in equation (9).

The numerical computation of example 2 by formula (11) is as follows:

Log 13,500 =	4. 1303
$0.0259 \times (12.0 - 9.8) =$	. 0570
Log $13{,}500 - 2.2 \times 0.0259 =$	4. 0733 = log 11,840

and 11,840 pounds per square inch is the adjusted value.

The principle of the graphical solution of case 1 is to plot the two known strength values over their corresponding moisture-content values on semilogarithmic paper, and from the line connecting these

points read the strength value corresponding to a third moisture content. When one of the moisture-content values is above the intersection-point value, the corresponding strength value is to be plotted at the intersection point.

In case 2 the principle is to plot the one known strength value at the corresponding moisture content and through this point to draw a line with the inclination defined by an assumed or estimated value of K. Then the strength value for a second moisture content is read from this line.

It is now evident that the principal difference between the two cases is that in case 1 the slope of the line, which is the value [14] of K, is determined from the data of the problem itself, whereas in case 2 the appropriate value of K has to be estimated from other data.

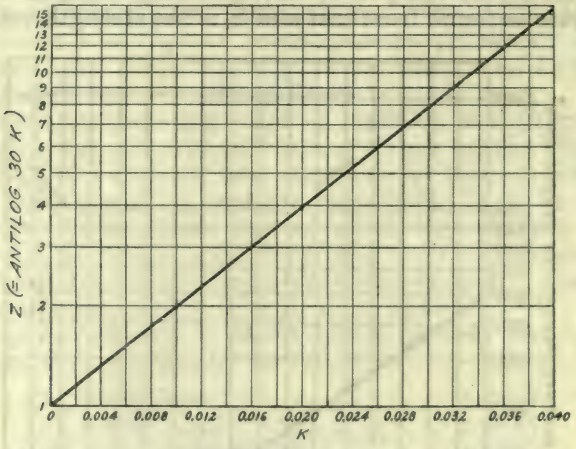

FIGURE 35.—Chart for use in constructing lines of specified slope K on semilogarithmic paper

SPECIAL DIAGRAM FOR USE IN MAKING ADJUSTMENTS

The methods applied in examples 1–A, 1–B, and 2 afford illustrations of the principles involved in making adjustments by the exponential formula. However, such adjustments can be handled even more simply by the use of special diagrams, such as Figure 36. The use of this diagram can be illustrated by applying it to the previous examples.

EXAMPLES OF THE USE OF FIGURE 36

EXAMPLE 1–A

Tests of Sitka spruce in the green condition and at 8.9 per cent moisture content gave values for maximum crushing strength of 2,600 and 5,770 pounds per square inch, respectively. The intersection-point moisture-content value M_p for Sitka spruce is 27 per cent. What would have been the strength value if tests had been made at 12 per cent moisture?

[14] The figures underscored in the computations of examples 1–A and 1–B (p. 66) are values of K.

The ratio R of the known strength values is 2.21, which equals $\frac{5,770}{2,600}$. The difference between the moisture-content values given is 18.1, which equals 27.0–8.9, and the higher moisture content

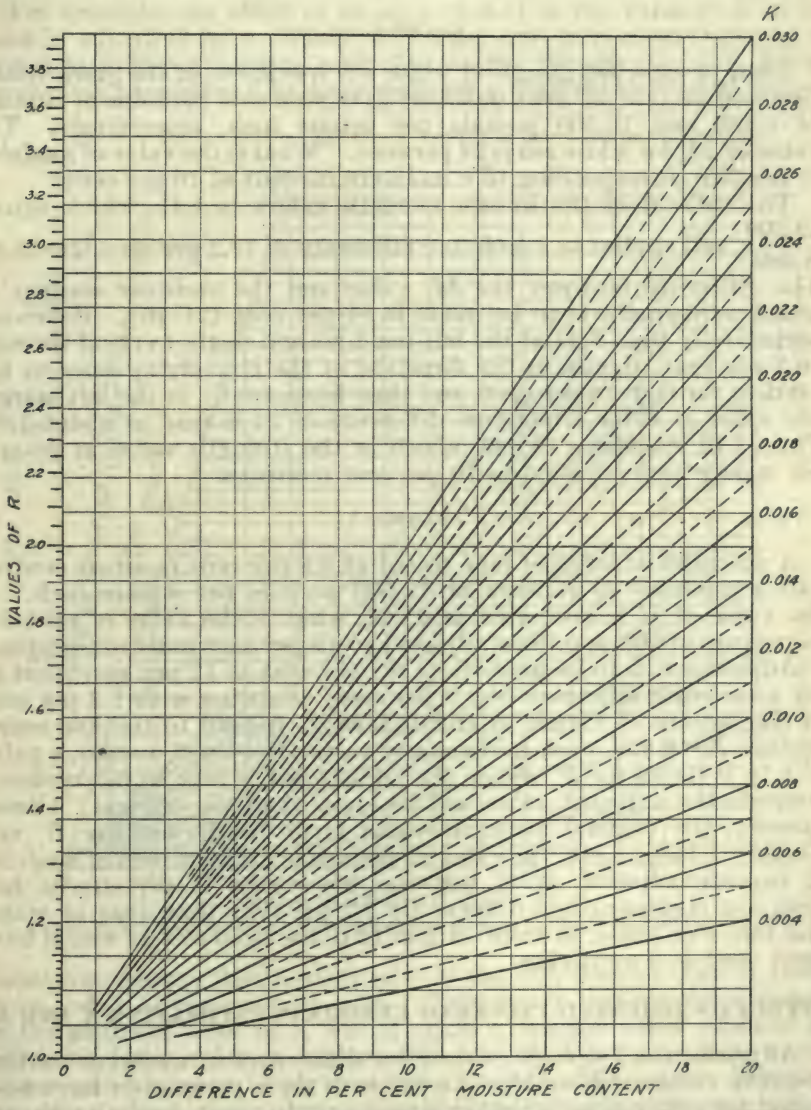

FIGURE 36.—Chart for use in making strength-moisture adjustments. (For examples see pp. 68 to 70)

(27 per cent) minus that to which adjustment is to be made (12 per cent) is 15 per cent. The R of 2.21 applies then to a moisture difference of 18.1, and the value of R for a moisture difference of 15 is to be found:

Starting with 2.21 at the left-hand margin of Figure 36 and following horizontally to the vertical representing 18.1 per cent moisture

difference, the value of K (0.019) is found on one of the converging lines. Following this line to its intersection with the vertical through 15 per cent and thence horizontally to the left-hand margin, an adjusted R of 1.93 is read and $1.93 \times 2{,}600 = 5{,}020$ pounds per square inch, which is the strength value adjusted to 12 per cent moisture.

EXAMPLE 1–B

Tests of matched groups of white ash specimens in the green condition and at 13.8 per cent moisture gave values of modulus of rupture of 8,880 and 12,500 pounds per square inch, respectively. The value of M_p for white ash is 24 per cent. What is the value of modulus of rupture corresponding to a moisture content of 10 per cent?

The ratio R of the known strength values is 1.41, which equals $\frac{12{,}500}{8{,}880}$, and applies to a moisture difference of 10.2 per cent (24–13.8). The difference between the M_p value and the moisture content to which adjustment is to be made is 14 per cent (24–10). Following horizontally from 1.41 at the left-hand margin to the vertical through 10.2 per cent, thence in the direction of the converging lines to the vertical through 14 per cent, and then horizontally to the left margin the value of R for a moisture difference of 14 is read as about 1.61. Then $1.61 \times 8{,}880 = 14{,}300$, which is the strength value in pounds per square inch adjusted to 10 per cent moisture.

EXAMPLE 2

A specimen of longleaf pine tested at 9.8 per cent moisture content had a modulus of rupture of 13,500 pounds per square inch. If the value of K is estimated as 0.026, what is the value of modulus of rupture of this specimen adjusted to 12 per cent moisture content?

Adjustment is to be made from 9.8 per cent to 12 per cent; that is, for a moisture difference of 2.2 per cent. Starting with 2.2 per cent at the bottom of Figure 36 and following upward to the line representing $K = 0.026$, then horizontally to the left-hand margin, a value of 1.14 is found for R. Since the adjustment is to a higher moisture content, the adjusted value will be lower than the original. Consequently, the original strength value must be divided by R, and $13{,}500 \div 1.14 = 11{,}840$, the value in pounds per square inch of modulus of rupture adjusted to 12 per cent moisture. If adjustment had been to a moisture content lower by 2.2 per cent than that at which the test was made, as from 14.2 to 12.0, the ratio of 1.14 would have been used as a multiplier.

EFFECT ON ADJUSTED VALUES OF ERRORS IN ESTIMATING K AND M_p

Adjustment of strength values for differences in moisture content requires values of K or M_p. As values of these parameters have been found for only a few species, it is necessary in many cases to estimate the value of one or the other of them. Also K, and probably M_p, varies for different specimens of a species, and the known values of these parameters may not be exactly correct for the test values to be adjusted. Consequently, a consideration of the effect of errors in estimates of K and M_p on the accuracy of the adjusted strength values is pertinent.

EFFECT OF ERROR IN K

It can be shown that the effect of an error in estimating the value of K to be used in case 2 problems increases in the manner indicated by Figure 37 with the error and with the difference between the moisture-content values from and to which adjustment is to be made.

For example, the effect of an error of 0.01 in the value of K to be used in adjusting for a difference of 5 per cent in moisture content is found as follows: Starting with 0.01 at the bottom (fig. 37), follow upward to the inclined line representing a difference of 5 per cent in

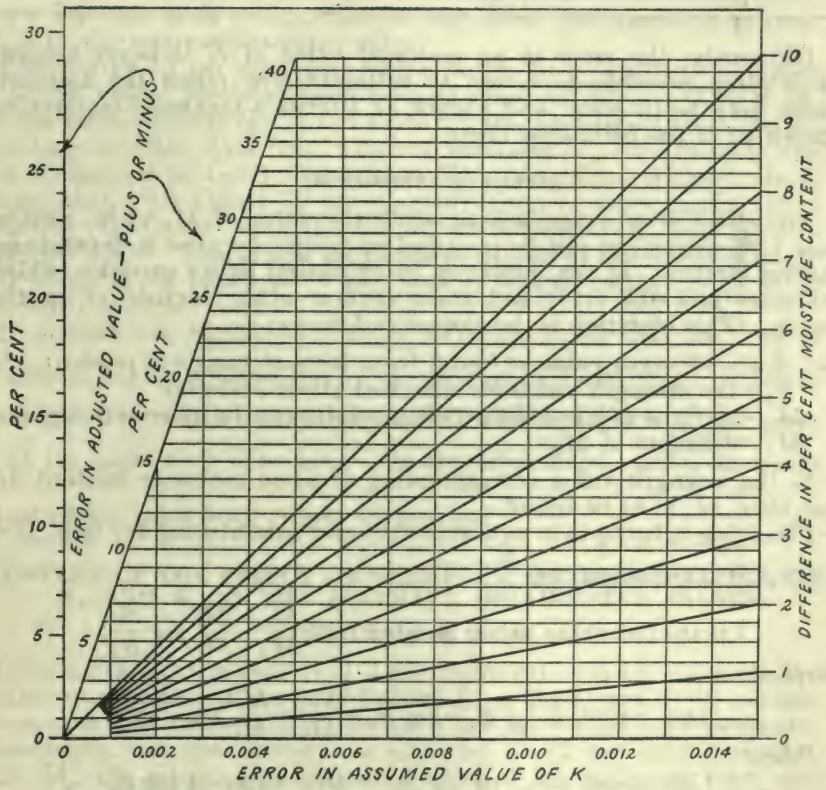

FIGURE 37.—Relation of error in adjusted strength value to error in assumed value of K

moisture content, then horizontally to the left, where values of about +12 and −11 per cent are read. This means that the error of 0.01 in the assumed value of K would cause a strength value obtained by adjusting for a moisture-content difference of 5 per cent to be about 12 per cent higher or 11 per cent lower than the true value. Whether the adjusted is higher or lower than the true value depends on whether adjustment is made to a higher or to a lower moisture content and on

whether the assumed value of K is too large or too small according to the following scheme:

Error in assumed value of K	Adjustment made to—	Error in adjusted value
+	Higher moisture content	−
+	Lower moisture content	+
−	Higher moisture content	+
−	Lower moisture content	−

Obviously, the error in an assumed value of K is never known. It is often possible, however, to estimate how much the assumed value may be in error, and Figure 37 affords a means of computing the effect of the estimated error.

EFFECT OF ERROR IN M_p

The effect of an error in estimating the value of M_p to be used in case 1 problems can not be pictured so simply because it depends on several factors. It can, however, be expressed by an equation which indicates how the error and these several other factors affect the result. This equation is developed as follows:

Let S_1 = a strength value as found from tests at moisture content M_1.
S_p = the strength value for matched green material.
M_p = the true value of the per cent moisture at the intersection point.
M_q = estimate of M_p.

S_2 the strength value corresponding to some moisture content M_2 less than M_p is to be found.

Changing subscripts in equation (10) and substituting for ($\log S_1 - \log S_p$) its equivalent, $\log \frac{S_1}{S_p}$:

$$\text{Computed value of } \log S_2 = \log S_p + \frac{M_q - M_2}{M_q - M_1} \log \frac{S_1}{S_p};$$

similarly,

$$\text{true value of } \log S_2 = \log S_p + \frac{M_p - M_2}{M_p - M_1} \log \frac{S_1}{S_p}.$$

Then

$$\text{Computed value of } \log S_2 - \text{true value of } \log S_2$$

$$= \log \frac{\text{computed value of } S_2}{\text{true value of } S_2}$$

$$= \left(\frac{M_q - M_2}{M_q - M_1} - \frac{M_p - M_2}{M_p - M_1} \right) \log \frac{S_1}{S_p}$$

$$= \frac{(M_2 - M_1)\ (M_q - M_p)}{(M_p - M_1)\ (M_q - M_1)} \log \frac{S_1}{S_p} \qquad (12)$$

or

$$\log \frac{\text{computed value of } S_2}{\text{true value of } S_2} = \mathrm{A} \log \frac{S_1}{S_p}, \qquad (13)$$

where $\mathrm{A} = \frac{(M_2 - M_1)\ (M_q - M_p)}{(M_q - M_1)\ (M_q - M_1)}$.

Equation (12) shows that the error in the computed value of log S_2, and hence the percentage error in the adjusted value S_2, is greater:

(1) The greater is $M_q - M_p$, the error in the assumed value of moisture content at the intersection point.

(2) The greater is $M_2 - M_1$, the difference in moisture content for which adjustment is made.

(3) The greater is $\frac{S_1}{S_p}$, the increase in the strength value produced by drying to the moisture content M_1.

(4) The less is M_p, the moisture content at the intersection point.

(5) The less is $M_p - M_1$; that is, the closer the moisture content M_1 is to the intersection-point value.

Frequently 12 per cent moisture is taken as a standard to which to adjust values resulting from tests of seasoned wood. Also if M_p for the particular species is not known from mechanical tests and no shrinkage or other data from which to estimate M_p are available, the best estimate is probably the average of known values, which is about 24 per cent. In Figure 38 are plotted values of the quantity A of equation (13) for $M_q = 24$, $M_2 = 12$, $M_1 = 2$ to 18 per cent, and $M_p = 20$ to 28 per cent. This graph simplifies estimates of the limits of accuracy when M_q is taken as 24 per cent in making adjustments to 12 per cent moisture.

In considering Figure 38 it must be remembered that the error is measured, not by A alone, but by the product of A and $\log \frac{S_1}{S_p}$. Hence, although A increases numerically as M_1 increases above 12 per cent, $\frac{S_1}{S_p}$ at the same time decreases. On the other hand, as M_1 decreases below 12 per cent, both A and $\frac{S_1}{S_p}$ increase.

EXAMPLES OF THE EFFECT OF ERRORS IN ESTIMATED VALUES OF M_p AND K ON THE ACCURACY OF ADJUSTED VALUES

EFFECT OF ERROR IN M_p

United States Department of Agriculture Bulletin 556 (7) gives the maximum crushing strength of balsam fir as 2,400 and 6,640 pounds per square inch in the green condition and at 4.8 per cent moisture, respectively. If the strength is adjusted to 12 per cent moisture, using M_q, the assumed or estimated value of M_p as 24 per cent, and the true value of M_p is between 20 per cent and 28 per cent, what are the limits of error in the adjusted value?

$$S_1 = 6{,}640,\ S_p = 2{,}400 \text{ and } \log \frac{S_1}{S_p} = \log \frac{6{,}640}{2{,}400} = 0.442$$

From Figure 38,

for $M_1 = 4.8$

$A = 0.098$ if $M_p = 20$

$A = -0.067$ if $M_p = 28$

Then

$$0.098 \times 0.442 = 0.0433 = \log 1.10$$
$$-0.067 \times 0.442 = -0.0296 = \log 0.93$$

and the estimate is that S_2, the value of maximum crushing strength adjusted to 12 per cent moisture with 24 per cent as the assumed value

of the moisture content at the intersection point will be between 93 and 110 per cent of the true value if the true intersection point moisture content is not less than 20 nor greater than 28 per cent.

As another example, United States Department of Agriculture Bulletin 556 (*7*) gives 2,060 and 3,400 pounds as the maximum crushing

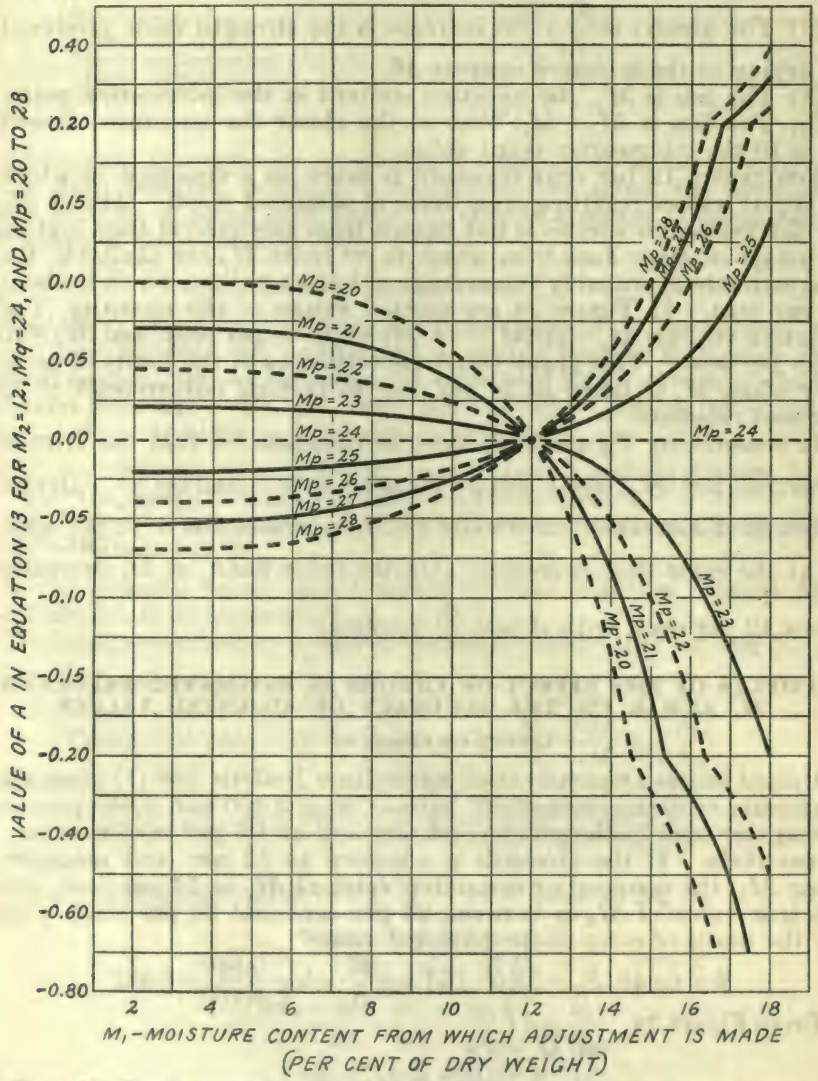

FIGURE 38.—Chart for estimating effect on adjusted strength value resulting from error in estimating the intersection-point moisture content (M_p)

strength of alpine fir green and at 15.9 per cent. Here $S_1=3,400$; $S_p=2,060$.

$$\text{Log}\frac{S_1}{S_p}=\frac{3,400}{2,060}=0.217$$

From Figure 38 for $M_1 = 15.9$

$A = 0.49$ if $M_p = 20$

$A = 0.16$ if $M_p = 28$

$-0.49 \times 0.217 = -0.106 = \log 0.78$

$0.16 \times 0.217 = 0.035 = \log 1.08$

and S_2, the value of maximum crushing strength adjusted to 12 per cent moisture, is estimated as being between 78 and 108 per cent of the true value if the true intersection point is not less than 20 nor greater than 28 per cent moisture. In other words, under this condition -22 per cent and $+8$ per cent are the limits of error in S_2.

EFFECT OF ERROR IN K

It is interesting to compare the estimates of error of solution of these two examples with errors that might result if an estimated or assumed value of K rather than of M_p were used. The best estimate of a value of K for such use is the grand average of the values given in Table 24 for maximum crushing strength or about 0.025 and from a consideration of the range of average values in Table 24, it is estimated that the true value of K for an individual species might differ from this grand average by as much as ± 0.009. For such an error in K, Figure 37 indicates errors in the adjusted values of about $+16$ or -14 per cent for the first example and $+8$ or $-7\frac{1}{2}$ per cent for the second. Ordinarily, the error in the estimated value of K probably would not exceed ± 0.007, and the error of adjusted value would be correspondingly less. Also since K is smaller for most other properties the error in applying a general average value of K to some particular species will be less for other properties than for maximum crushing strength.

The errors in the illustrations given in this and the preceding section are about as large as are likely to occur, and in most instances it will be possible to estimate the value of K or M_p with such accuracy that error in the adjusted value of a strength property will be much less.

LIMITATIONS OF ADJUSTMENT METHODS

The preceding discussion of the errors that may occur in making moisture-strength adjustments has been presented to enable those making such adjustments to estimate what errors may be incurred and thereby to appraise the accuracy of an adjusted value. It is to be remembered that the adjustment methods are applicable only to results on specimens in which the moisture is very nearly uniformly distributed. Such distribution does not ordinarily obtain in pieces whose average moisture content is near the intersection-point value, and the adjustment of test results obtained at moisture-content values between about 15 or 16 per cent and the intersection-point values is subject to errors of considerable magnitude.

The adjustment methods have been derived from wood in which no abnormal amounts of resin or other infiltrated substances were present, and caution needs to be exercised in applying them to wood containing exceptional amounts of such substances. The effect of moisture on the strength properties of wood that contains abnormal amounts of resin has not been thoroughly investigated. Such tests as have been made on material of this character indicate that strength-moisture relations are erratic. This may be due to inaccu-

racies in moisture determinations in such instances. If the amount of moisture held in the wood substance could be determined accurately such material might display as definite strength-moisture relations as wood without resin or with only normal amounts of resin. It has been found that in some species that contain large amounts of other infiltrated substances, these substances have the effect of raising the strength of green wood without exerting a corresponding effect on dry material. Consequently, such wood is increased in strength by drying less than is wood that does not contain such substances.

Although the methods of adjustment outlined are believed to be the best that is now possible to devise, they should be used with care and judgment and with a full realization of the possibility of error. It is evident that in all cases the risk of error is least when the difference between the moisture-content values from and to which adjustment is made is small. Necessity for adjustments for any but comparatively small differences in moisture content can ordinarily be avoided by care in conditioning specimens for test. Usually seasoning to a moisture content not far from 12 per cent can be readily accomplished either by natural (air) or artificial (kiln or conditioning chamber) drying, and 12 per cent is suggested as a standard moisture content at which to test seasoned specimens.

In tests, such as may be made for the determination of the effect of a preservative, fireproofing, or other treatment, it is advisable to season both control and treated specimens to equilibrium under atmospheric conditions simulating those that will obtain in service. In this way the need, in analyzing results to determine the effect of the treatment, for adjustments, other than for small differences in moisture content, will be avoided. Furthermore, the treatment may so modify the hygroscopicity of the wood that control and treated specimens will not come to equilibrium at the same moisture content, and in such instances it may be proper to compare the test results directly without adjustment for the moisture difference.

OTHER PHASES OF STRENGTH-MOISTURE RELATIONS

The preceding discussion has been concerned with the relation between moisture content and strength properties in pieces of wood that are free from defects and in which the moisture is practically uniformly distributed. The methods of adjustment developed are applicable to such pieces only and not to pieces containing defects or to pieces in which the moisture is nonuniformly distributed, that is, pieces in which a moisture gradient of considerable magnitude exists. Two important phases of strength-moisture relations in wood remain for consideration. These are the instances when (1) the moisture content is nonuniformly distributed and considerable moisture gradient exists between the interior and exterior parts of the cross section, and (2) when the piece contains such defects as knots, cross grain, shakes, or checks.

THE EFFECT OF NONUNIFORMLY DISTRIBUTED MOISTURE ON THE STRENGTH OF WOODEN MEMBERS

When a piece of wood is held for a long period under nearly constant conditions of atmospheric temperature and humidity, all parts of it reach approximate equilibrium, and only small variations in

moisture content between parts obtain. Normally, however, wood is not held under constant conditions, and usually drying is carried out in such a manner as to produce moisture gradients of considerable magnitude during the time the piece is approaching equilibrium. The results of tests on chestnut specimens with moisture nonuniformly distributed are illustrated in Figure 5. In this instance, the effect of the greater dryness of the outer parts of the specimens resulted in a strength-moisture curve well above that for specimens with moisture uniformly distributed. As may be seen from Figure 5, the strength of specimens with a nonuniformly distributed moisture content of 42 per cent was as great as that of specimens with a uniformly distributed moisture content of 18 per cent, and for specimens with nonuniform moisture content averaging about 25 per cent the strength was as great as for those having a uniformly distributed moisture content of 14 per cent. That wood tested in a partially seasoned condition and displaying large moisture gradients does not always yield results similar to these is demonstrated by a recent investigation.

The specific object of this investigation was to obtain information applicable to values from tests of partially and nonuniformly seasoned wood. Such information would prove valuable since preservative and other treatments of timber frequently dry the surface to a low moisture content and leave the moisture content progressively higher toward the center of the piece. Conclusions concerning the effect of such treatments on strength properties of wood could be reached very quickly if specimens could be tested soon after treatment and the results so adjusted as to be comparable to those from control specimens. Again, telephone poles of different species and different groups of poles of the same species have been tested at various stages of seasoning. The data from these tests would be of much greater utility if they could be adjusted to a strictly comparable basis.

The tests of the effect of partial seasoning were made on pole and rectangular (2 by 4 inches in cross section) specimens. The species of wood were chestnut, Douglas fir, loblolly pine, shortleaf pine, and tamarack.

Static-bending and compression-parallel-to-grain tests were made on partially dry and on matched green control specimens. The 2 by 4 inch specimens for test in the partially seasoned condition were prepared in 3 by 4 inch size, and the wide faces were coated with a preparation to retard drying so that the principal drying would take place from the narrow faces. When the specimens had been dried for the requisite period of time one-half inch was removed from each of their wide faces and the tests made. This resulted in test specimens 2 by 4 inches in cross section whose moisture content was nearly uniform across the width or narrow dimension but varied from a comparatively low value at each narrow face to a higher value at the middle. The pole specimens for test in the partially seasoned condition were dried in such a way as to produce a comparatively low moisture content at the surface, increasing to a higher value at the center.

The more important of the data on 2 by 4 inch specimens of chestnut and loblolly pine are presented in Figures 39 to 43, inclusive.

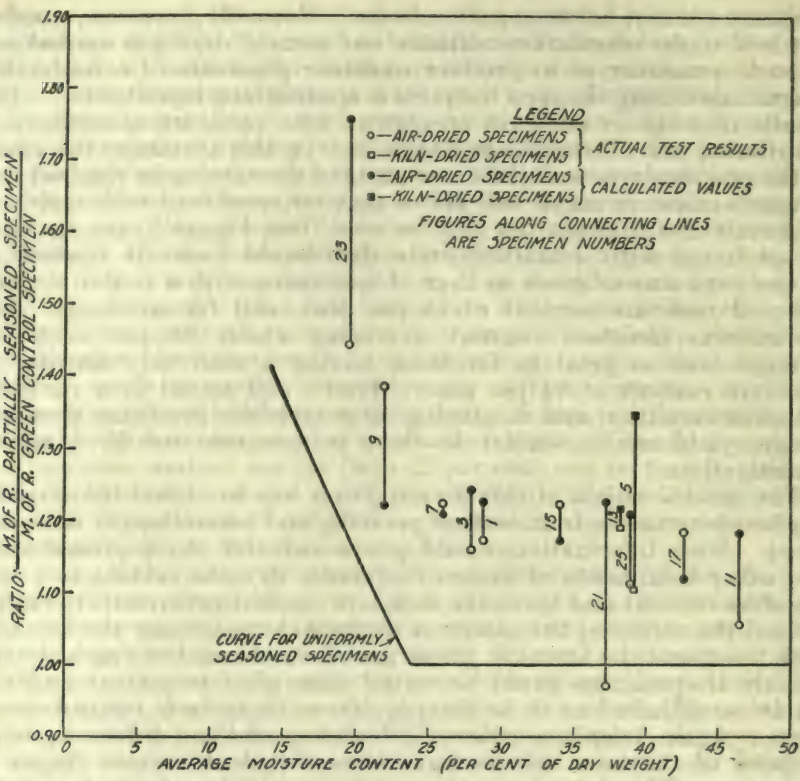

FIGURE 39.—Results of the determination of the modulus of rupture of nonuniformly seasoned 2 by 4 inch specimens of chestnut. For data on moisture distribution, see Table 25

TABLE 25.—*Moisture distribution data for nonuniformly seasoned 2 by 4 inch specimens of chestnut plotted in Figures 39, 40, and 41*

Specimen	Moisture content of successive slices from compression face of static bending specimen				
	First 1/8 inch	Second 1/8 inch	Second 1/4 inch	Third 1/4 inch	Fourth 1/4 inch [1]
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
No. 1	12.7	15.8	18.3	22.3	26.2
No. 3	12.6	16.0	18.1	20.4	25.0
No. 5	8.4	12.5	14.9	19.3	27.1
No. 7	13.1	15.8	18.3	21.1	24.7
No. 9	13.7	16.2	18.0	19.7	21.7
No. 11	11.5	15.3	21.4	39.8	102.4
No. 13	9.7	12.2	15.1	22.2	33.7
No. 15	13.8	16.5	19.0	23.0	29.0
No. 17	13.8	16.0	19.8	25.5	33.6
No. 19	11.1	13.3	19.5	30.0	50.5
No. 21	11.4	14.8	17.8	22.2	29.2
No. 23	9.6	11.6	13.8	16.0	18.1
No. 25	12.4	15.4	18.1	23.6	31.6

[1] The average moisture content in the second inch of all specimens was above the intersection-point value except that in the second inch of specimen No. 23, which was 20.5 per cent.

In each of these diagrams, the ratios of the strength of a partially seasoned specimen to the strength of its own green control specimen are plotted over the average moisture content of the partially seasoned specimen. There is also shown for comparison a moisture-strength curve for uniformly seasoned pieces. Where suitable data on specimens from the same logs as the partially seasoned specimens were available, they were used in establishing the moisture-strength curve for uniformly seasoned specimens.

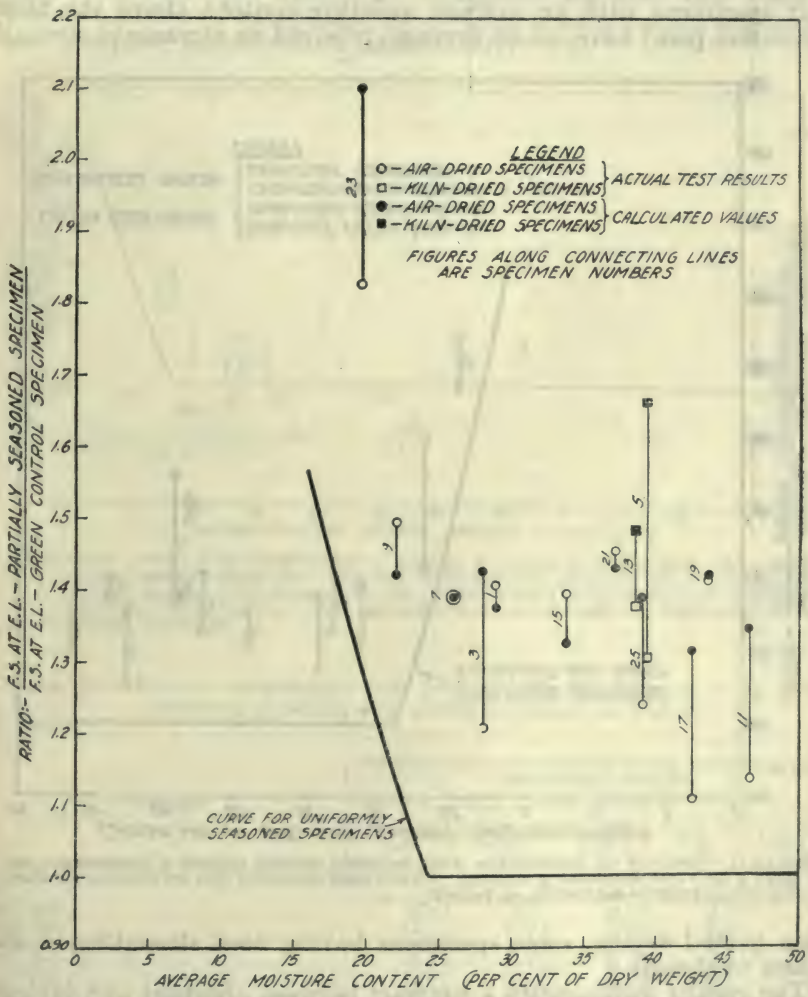

FIGURE 40.—Results of the determination of the fiber stress at elastic limit in static bending of nonuniformly seasoned 2 by 4 inch specimens of chestnut. For data on moisture distribution, see Table 25

The data demonstrate that the strengths of different species are differently affected by partial seasoning, as may be seen from a comparison between chestnut and loblolly pine. Figures 39, 40, and 41 show the results of tests on chestnut. The fact that in these dia-

grams the points are consistently well above the moisture-strength curve for uniformly seasoned specimens demonstrates that the specimens with moisture nonuniformly distributed were much higher in strength than they would have been had the moisture content averaged the same but been uniformly distributed in the cross section, and confirm with respect to chestnut the results shown in Figure 5.

Figures 42 and 43 present similar data for loblolly pine and show that specimens with an average moisture content above the fiber-saturation point have, on an average, received no increase in strength

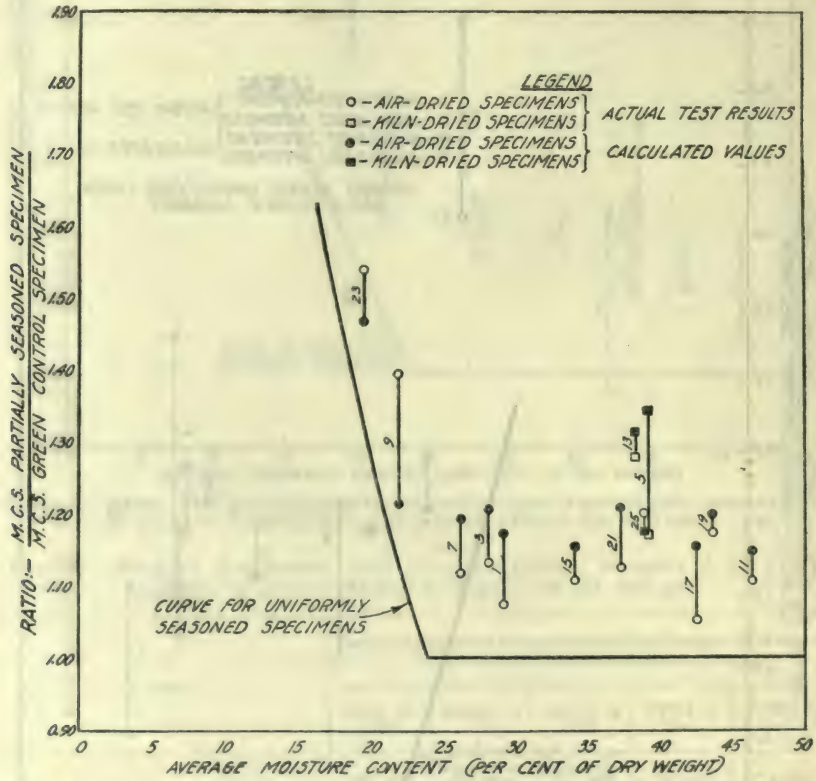

FIGURE 41.—Results of the determination of the maximum crushing strength of nonuniformly seasoned 2 by 4 inch specimens of chestnut. Figures along connecting lines are specimen numbers. For data on moisture distribution, see Table 25

from partial drying, some specimens having been strengthened and others weakened.

The results demonstrate a contrast between chestnut and loblolly pine with respect to the effect of partial seasoning. The other species tested are intermediate. This difference with respect to the effect of partial seasoning is due to variations in the way adjacent layers differing in moisture content act together when strained in compression. The cooperation of these layers depends on their stress-strain relations.

Two types of behavior of wood under compressive stress and strain, either in pure compression or in bending, are as follows:

TYPE A.—Maximum stress is reached at comparatively small deformation, and the stress decreases rapidly with small additional deformation; the strain, or deformation, soon becoming localized at a single point or in a small region. When local failure has once occurred, not enough stress can be sustained to cause the formation of other failures. This type of behavior is more common in dry wood than in green and more common in coniferous species than in hardwoods. Its extreme is exemplified by very dry wood, in which maximum stress is reached at a small deformation and sudden and complete failure occurs immediately.

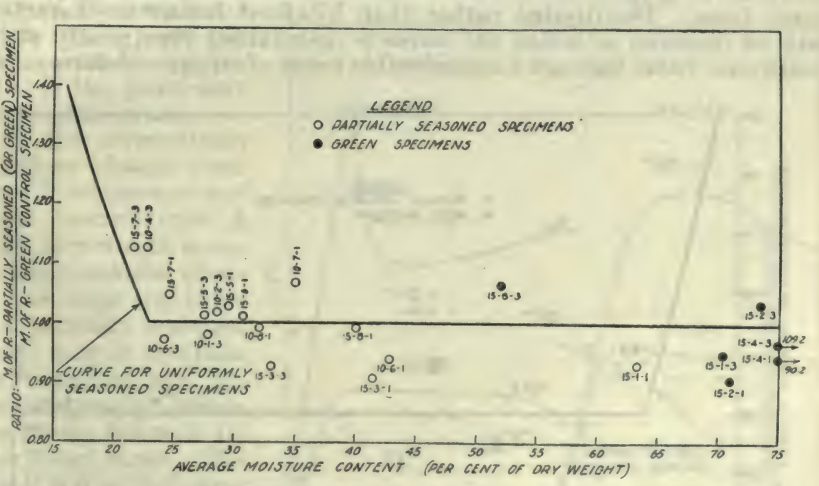

FIGURE 42.—Results of the determination of modulus of rupture of nonuniformly seasoned 2 by 4 inch specimens of loblolly pine. The solid circles represent specimens that were intended to be partially seasoned with comparatively low moisture content at the surface but were found to have moisture content values above the intersection point value throughout. See Table 26 for data on moisture distribution

TABLE 26.—*Moisture distribution data for nonuniformly seasoned 2 by 4 inch specimens of loblolly pine plotted in Figures 42 and 43*

Specimen	Moisture content of successive slices from compression face of static bending specimen				
	First ⅛ inch	Second ⅛ inch	Second ¼ inch	Third ¼ inch	Fourth ¼ inch [1]
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
No. 10–1–3	12.7	16.8	22.9	25.7	27.9
No. 10–2–3	14.1	18.1	23.3	25.6	27.1
No. 10–4–3	12.0	17.8	22.6	25.2	
No. 10–6–1	17.2	45.6	43.4	59.4	55.8
No. 10–6–3	14.1	16.0	20.6	24.1	26.0
No. 10–7–1	14.7	17.7	23.0	36.7	56.8
No. 10–8–1	13.1	16.9	20.7	24.6	28.9
No. 15–1–1	17.4	21.7	26.9	25.3	36.6
No. 15–3–1	12.6	17.0	20.6	26.9	33.6
No. 15–3–3	20.0	30.8	44.0	57.2	50.6
No. 15–5–1	15.4	19.1	21.5	23.2	24.5
No. 15–5–3	17.9	28.6	31.7	35.6	29.0
No. 15–6–1	22.4	26.2	29.0	29.8	31.2
No. 15–7–1	12.9	15.9	21.6	27.5	34.3
No. 15–7–3	14.2	16.0	18.3	21.6	24.0
No. 15–8–1	20.8	28.4	29.4	46.0	43.6

[1] The moisture content in the second inch of all specimens was above the intersection-point value.

TYPE B.—Maximum stress does not occur until a comparatively large deformation has taken place, stress decreases but slowly with further increase in deformation, deformation continues to be well distributed longitudinally for a time but finally becomes localized at a number of points, and numerous failures appear simultaneously or in close succession before there is an appreciable decrease in stress. This type of behavior is more common in green wood than in dry and more common in hardwoods than in conifers. It is exhibited by both green and air-dry wood of such species as hickory and reaches its extreme in hickory that has been obtained from near the base of some trees. Distributed rather than localized failure is characteristic of material in which the stress is maintained very nearly at its maximum value through a considerable range of strain or deformation.

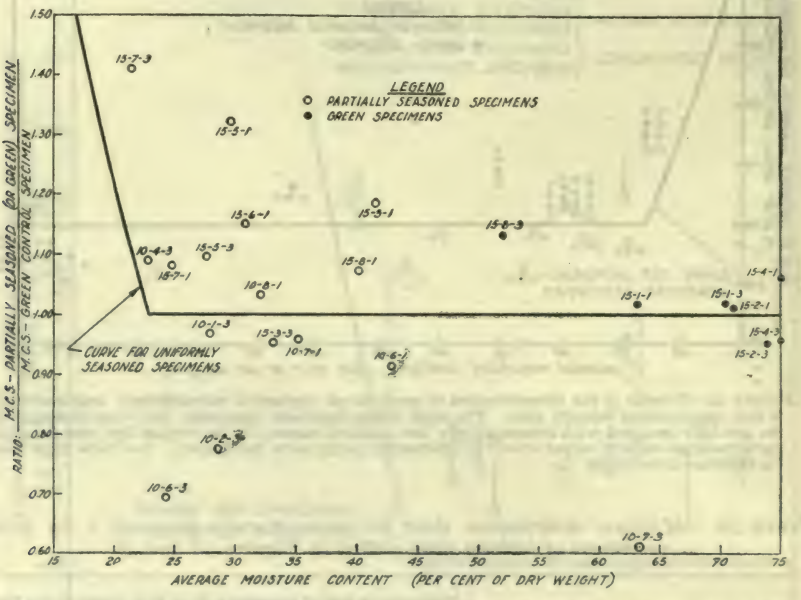

FIGURE 43.—Results of the determination of maximum crushing strength of nonuniformly seasoned 2 by 4 inch specimens of loblolly pine. The solid circles represent specimens that were intended to be partially seasoned with comparatively low moisture content at the surface but were found to have moisture-content values above the intersection-point value throughout. See Table 26 for data on moisture distribution

The stress-strain relation corresponding to type A behavior is illustrated by the diagram for air-dry loblolly pine as shown in Figure 44, while that for type B is illustrated by the diagrams for green loblolly pine and for green and air-dry chestnut. The diagrams in this figure were taken from actual tests and are typical with respect to the shape of the stress-strain curves but not with respect to the relative amounts of deformation at maximum stress.

If the stress-strain relations are of type B both for green and for air-dry material, as illustrated for chestnut in Figure 44, all or several of the successive layers of a nonuniformly seasoned piece may develop their maximum or nearly their maximum stress at the same deflection. This is obviously true for pieces loaded in compression parallel to grain. How it may also be true of beams can be seen from the fact

that when tension failure occurs in a beam the neutral plane has moved downward and the deformation not only at the upper surface but for a considerable distance below it comes into the range within which the stress is maintained at very nearly its maximum. Such a nonuniformly seasoned piece would carry a larger load either in compression or in bending than if it were thoroughly green.

If type A stress-strain relations obtain at all degrees of dryness, the parts of a nonuniformly seasoned piece loaded in compression parallel to grain may not develop their maximum stress at the same deflection with the result that the maximum load for the piece is less than the sum of the maximum loads for its parts and may actually be less than if the piece were thoroughly green.

If the stress-strain relations change from type B for green or wet wood toward type A with decrease in moisture content, the stress in the drier top layer of a partially seasoned beam may in test pass its maximum and decrease greatly before the layers below it attain a high stress. The result is that the layers of different degrees of dryness successively reach their maximum stress and fail, and the beam may be no stronger or may be actually weaker than if it were thoroughly green.

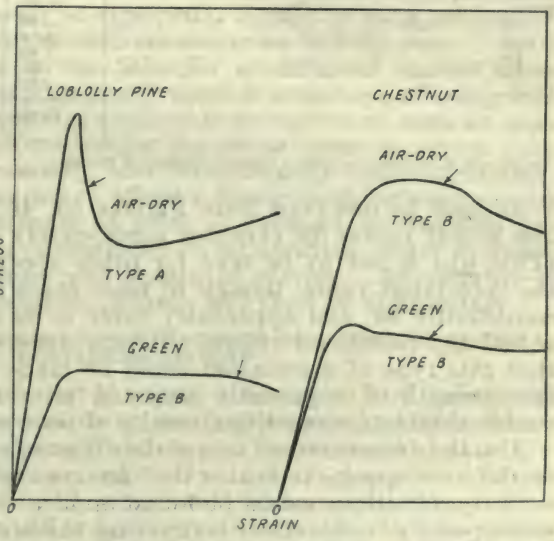

FIGURE 44.—Shape of stress-strain diagrams for green and air-dry loblolly pine and chestnut under compressive stress. Arrows indicate first visible failure

Different types of behavior of nonuniformly seasoned pieces in compression parallel to grain are illustrated by loblolly pine (fig. 43) and chestnut (fig. 41), respectively. Figure 43 indicates that, on an average, loblolly pine was not increased in strength by partial seasoning. Figure 41 shows, on the contrary, that chestnut was increased in strength although in only 3 cases out of 13 was the actual strength value as high as it would have been had each part carried the load (calculated value) corresponding to its moisture content.

Figures 39 and 40 show certain calculated values in addition to actual results from bending tests. These values were obtained by multiplying the moment of inertia of each of the parts of the beam whose moisture content was separately determined into the estimated strength value (modulus of rupture or fiber stress at elastic limit) at that moisture content and dividing the sum of these products by the moment of inertia of the entire section. A sample computation is shown in Table 27.

TABLE 27.—*Example of calculated values for modulus of rupture*

[Specimen 2 by 4 inches. Modulus of rupture of green control specimens 5,000 pounds per square inch. Moisture content of successive slices counting from top of the beam are given in column 3. Distribution of moisture assumed to be symmetrical about horizontal center line of section]

Thickness of slice	Moment of inertia of two symmetrically located slices	Moisture content	Modulus of rupture	Moment of inertia times modulus of rupture
		Per cent	*Lbs. per sq. in.*	
¼ inch	1.878	13.8	7,150	13,430
Do	1.643	16.5	6,500	10,680
¼ inch	2.646	19.0	6,000	15,880
Do	1.896	23.0	5,170	9,800
Do	1.271	29.0	5,000	6,355
¼ inch	1.333	39.9	5,000	6,665
	10.667			62,810

62,810÷10.667=5,890=calculated value of modulus of rupture.

As may be observed from Figures 39, 40, and 41, the calculated and actual values for chestnut agree closely in only a few instances. (This was found to be true for other species also.) Furthermore, the calculated value, though in most cases above the actual, is not consistently so, and apparently there is no correlation between the actual and calculated values. Hence, there seems to be little chance that this type of calculation could be made the basis for predicting the strength of a partially seasoned piece or of reducing to some standard moisture condition results of tests on such a piece.

Also the demonstrated fact of the differing effect of partial seasoning on different species indicates that no one type of formula for making such computations would be found applicable to all species and that, consequently, methods of computing the strength of pieces of wood of a species when in a partially seasoned condition can be found, if at all, only after very extended experiments on that species.

CONCLUSIONS FROM THE TESTS OF WOODEN MEMBERS HAVING NONUNIFORMLY DISTRIBUTED MOISTURE

The tests of the strength of specimens with moisture nonuniformly distributed lead to the following conclusions:

A partially seasoned piece of wood whose average moisture content is above the fiber-saturation-point value may or may not be stronger and may conceivably be weaker than the same piece in the green condition. Whether increase in strength occurs as the result of such seasoning depends on the characteristics of the species and on numerous other factors. The available information indicates that the species most likely to be increased in strength are those in which, regardless of the degree of dryness, the stress in compression parallel to grain decreases but slowly as deformation is increased beyond that at which maximum stress occurs. However, the characteristics that determine whether or not wood of a species will be increased by such partial seasoning are not completely known. Consequently, it is not possible to classify species in this respect except from the results of tests. Chestnut specimens were appreciably strengthened by partial seasoning that did not reduce the average moisture content below the fiber-saturation-point value; loblolly pine similarly seasoned was on

the average no stronger than when green. Douglas fir rectangular and tamarack pole specimens showed some increase but less than chestnut. Available data are insufficient to indicate the effect of similar seasoning on shortleaf pine.

Timber partially seasoned to an average moisture content below the fiber-saturation-point value may or may not have higher strength than would be expected from the average moisture content. In the tests described, pole specimens of tamarack and chestnut and rectangular specimens of chestnut, shortleaf pine, and Douglas fir were usually higher in strength than would be expected from the average moisture content, whereas the results for pole specimens of shortleaf pine were lower than would be expected. Available data are insufficient to indicate the effect of such seasoning on loblolly pine.

Because of difference in the behavior of different species when partially and nonuniformly seasoned, there is little hope of being able to derive adjustment formulas applicable to results of tests on partially seasoned wood. No attempt should be made to adjust data derived from tests of partially and nonuniformly seasoned timber.

Material for tests intended to afford a comparison between species in the form of such products as poles or between treated and untreated timber should be conditioned to equilibrium under exposure approximately the same as will obtain in service. Adjustment of data for differences in moisture content will then be unnecessary.

MOISTURE AND ITS RELATION TO THE STRENGTH OF WOOD AND TIMBER CONTAINING DEFECTS

It has been emphasized that the tests of Groups 1 and 2 discussed earlier in this bulletin were made on small specimens free from defects and that the changes in strength shown and the methods of moisture-strength adjustment set up apply only to such material. Larger pieces free from defects and structural timbers with the defects commonly found therein differ distinctly from small, clear specimens with respect to strength-moisture relations.

The drying of small, clear specimens produces comparatively large increases in many strength properties because the wood fibers and other small elements of the structure are greatly increased in strength. Although in larger pieces and in pieces with such defects as knots, cross grain, and shakes, similar increase in the strength of the fibers takes place it is not fully effective in increasing the strength of the piece as a whole because drying almost invariably produces checks, particularly in pieces containing the pith of the tree, and also intensifies the effects of previously existing defects. The reason for this is found in the way moisture moves and in the way shrinkage takes place during drying.

With a given change of moisture content below the fiber-saturation point, the shrinkage of a piece of wood or the tendency to shrink differs according to the three principal directions with respect to the structure. The tendency to shrink is greatest in the tangential direction, less radially, and, except in abnormal material, such as compression wood,[15] is negligible longitudinally or along the grain.

[15] Compression wood consists characteristically of annual rings abnormally widened over a part of their circumference. In this widened portion, the summer wood constitutes a large proportion of the width of the ring, but the difference between spring wood and summer wood is less marked than in wood of normal structure. Compression wood occurs only in coniferous species and is formed principally on the lower side of leaning trees and the underside of limbs. In addition to abnormal longitudinal shrinkage, compression wood is characterized by specific gravity above normal and by a deficiency in certain strength properties.

The width of flat-grained or slash-sawn boards is principally tangential to the annual rings, and it is common observation that such boards shrink more in drying and undergo greater changes in width with subsequent fluctuations of moisture content than do edge-grained or quarter-sawn boards, whose width is radial. Owing to this same difference the circumference of a pole or log tends to be decreased by a greater percentage in drying than does the diameter, and stretching or checking is necessary to accommodate the circumference to the diameter. The same is true of sawed timbers that include the pith of the tree. Ordinarily, the wood is incapable of the necessary stretching, and consequently drying is accompanied by checking.

The drying of any piece of wood takes place from the outside, in consequence of which the outer portion acquires a tendency to shrink in advance of the interior. This is the principal cause of checking in pieces that do not contain the pith and enhances the checking of logs, poles, and other products in which the pith is present.

Under a given drying condition moisture moves at different rates in the principal structural directions. Movement is most rapid longitudinally and least tangentially, with that in the radial direction intermediate. An illustration of the effect of the more rapid longitudinal movement is afforded by the checks that form at the ends of lumber and timber during drying unless precautions are taken to retard drying from the ends. As a result of the rapid longitudinal movement, the material at and near the ends of the piece soon reaches a moisture content that demands shrinkage, but as shrinkage is resisted by the adjacent portions that have not reached such a moisture condition checking occurs at the ends of the piece.

The combined effect of the differences in moisture movement and shrinkage in the different directions and of the fact that the outer portions of any piece ordinarily reach a moisture content that demands shrinkage in advance of the interior is to stress the wood in compression and tension across the grain. The tension stresses cause checking and increase the extent of any shakes that may be present. Checking and extension of shakes reduce the area available to resist shearing stress parallel to the grain. Checking reduces the strength in longitudinal compression by separating the fibers and thus causes the loss of some of their mutual support against buckling. Decrease in adherence of fibers also lessens the tensile strength.

Shrinkage stresses and the resulting checking are at a minimum in small, clear pieces that are carefully dried. Ordinarily the larger the piece the more severe is the checking that takes place, and, consequently, large pieces, even when free from knots or cross grain so that the checks are parallel to the length, gain less strength in drying than do small specimens. The checks in the pieces having knots [16] and cross or spiral grain extend in directions inclined to the length of the piece. Also shrinkage stresses and checking in such pieces are enhanced by the fact that the movement of moisture to the lateral faces of the piece is in part along the length of the fibers and, consequently, larger differences in moisture content between the surface and the interior occur. Since longitudinal compression and tension stresses have components parallel and at right angles to these

[16] The weakening effect of knots in either green or seasoned timbers is due largely to the fact that the fibers within and surrounding them are not parallel with the length of the piece.

directions, the gain in fiber strength resulting from loss of moisture is further offset in such pieces.

These effects cause any lot of sawed timbers to be more variable in strength when seasoned than when green, and tests of similar groups of green and seasoned timbers have shown that although maximum and average strength values are higher for the seasoned material, minimum values are not appreciably raised by seasoning. A degree of cross grain that has little influence on timbers in the green condition may, because of the formation of checks, greatly affect a seasoned timber.

The statements of the preceding paragraph apply to sawed timbers. Checking and the stresses set up in drying have less effect on the strength of split or of naturally round timbers, such as poles and piling. In such pieces no movement of moisture to the surface along the length of the fibers occurs, and unless the piece is spiral grained, longitudinal stresses do not have components at right angles to the checks. Consequently, round timbers, unless they are spiral grained, are considerably increased in strength by seasoning (*1*) but not so greatly as small, clear specimens.

SUMMARY

This bulletin brings together data resulting from tests of the effect of moisture on the strength properties of wood as made by the Forest Service over a period of 25 years. The data are considered in detail, and from them a type formula to express the relation between uniformly distributed moisture content and various strength properties is derived. The application and limitations of this formula in adjusting test results for differences in moisture content are presented. The effect of partial seasoning on the strength of wood and the pitfalls which attend any attempt to adjust strength values when the moisture is nonuniformly distributed are set forth, as well as the effect of seasoning on the strength of timbers containing defects.

LITERATURE CITED

(1) BETTS, N. DE W.
1914. ROCKY MOUNTAIN MINE TIMBERS. U. S. Dept. Agr. Bul. 77, 34 p., illus.

(2) AMERICAN SOCIETY FOR TESTING MATERIALS.
1927. STANDARD METHODS OF TESTING SMALL CLEAR SPECIMENS OF TIMBER. SERIAL DESIGNATION D143–27. A. S. T. M. Standards. . . . 1927, Pt. II. Nonmetallic Materials, p. 627–663, illus.

(3) DUNLAP, F.
1914. DENSITY OF WOOD SUBSTANCE AND POROSITY OF WOOD. Jour. Agr. Research 2:423–428.

(4) Goss, O. P. M.
1913. MECHANICAL PROPERTIES OF WESTERN HEMLOCK. U. S. Dept. Agr., Forest Serv. Bul. 115, 45 p., illus.

(5) ———
1913. MECHANICAL PROPERTIES OF WESTERN LARCH. U. S. Dept. Agr., Forest Serv. Bul. 122, 45 p., illus.

(6) MARKWARDT, L. J.
1930. COMPARATIVE STRENGTH PROPERTIES OF WOODS GROWN IN THE UNITED STATES. U. S. Dept. Agr. Tech. Bul. 158, 39 p., illus.

(7) NEWLIN, J. A., and WILSON, T. R. C.
1917. MECHANICAL PROPERTIES OF WOODS GROWN IN THE UNITED STATES. U. S. Dept. Agr. Bul. 556, 47 p., illus.

(8) ——— and WILSON, T. R. C.
1919. THE RELATION OF THE SHRINKAGE AND STRENGTH PROPERTIES OF WOOD TO ITS SPECIFIC GRAVITY. U. S. Dept. Agr. Bul. 676, 35 p., illus.

(9) STAMM, A. J.
1929. DENSITY OF WOOD SUBSTANCES, ADSORPTION BY WOOD, AND PERMEABILITY OF WOOD. Jour. Phys. Chem. 33: 398–414, illus.

(10) ———
1929. FIBER-SATURATION POINT OF WOOD AS OBTAINED FROM ELECTRICAL CONDUCTIVITY MEASUREMENTS. Indus. and Engin. Chem., Analyt. Ed. 1: 94–97, illus.

(11) SUDWORTH, G. B.
1927. CHECK LIST OF THE FOREST TREES OF THE UNITED STATES, THEIR NAMES AND RANGES. U. S. Dept. Agr. Misc. Circ. 92, 295 p.

(12) TIEMANN, H. D.
1906. EFFECT OF MOISTURE UPON THE STRENGTH AND STIFFNESS OF WOOD. U. S. Dept. Agr., Forest Serv. Bul. 70, 144 p., illus.

(13) ———
1907. THE STRENGTH OF WOOD AS INFLUENCED BY MOISTURE. U. S. Dept. Agr., Forest Serv. Circ. 108, 42 p., illus.

(14) TRAYER, G. W., and MARCH, H. W.
1930. THE TORSION OF MEMBERS HAVING SECTIONS COMMON IN AIRCRAFT CONSTRUCTION. Natl. Advisory Com. Aeronaut. Ann. Rpt. (Tech. Rpt. 334) 49: 671–719, illus.

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TECHNICAL BULLETIN No. 281 FEBRUARY, 1932

EXPERIMENTS WITH INSECTICIDES FOR CODLING-MOTH CONTROL

BY

E. J. NEWCOMER
Senior Entomologist

AND

M. A. YOTHERS
Associate Entomologist
Division of Deciduous Fruit Insects
Bureau of Entomology

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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INTRODUCTION

The codling moth (*Carpocapsa pomonella* L.) is one of the most serious insect enemies of apples and pears in the United States. The numerous investigations of this pest that have been made have long ago shown the chief factors to be considered in its control. The introduction of new insecticides and the necessity for avoiding objectionable spray residues, as well as the demand for more economical and more effective treatments, however, have made continuous experimentation imperative.

Laboratory and orchard experiments in controlling the codling moth with sprays have been conducted by the Bureau of Entomology at Yakima, Wash., from 1919 to 1929, inclusive.[1] Some of the experiments are of only local or transient interest; the results of many others have a wider and more permanent application. The more important of these latter are brought together in this bulletin.

METHODS

The laboratory experiments with larvae were made in the manner already described by one of the writers (*5*).[2] Experiments with insecticides for destroying the eggs were made by thoroughly spraying pear leaves or apples upon which eggs had been deposited, hanging them out of doors under a roof in a free circulation of air, and examining them after unsprayed eggs of the same age had hatched.

[1] This work was done under the direction of A. L. Quaintance, at that time in charge of the Division of Deciduous Fruit Insects, Bureau of Entomology. From 1919 to 1922 the senior writer was assisted in these experiments by W. D. Whitcomb, formerly of the Bureau of Entomology, and from 1923 to 1929 by M. A. Yothers, of the bureau. The orchard experiments were made in several commercial apple orchards near Yakima through the generous cooperation of the owners of these orchards.

[2] Italic numbers in parenthesis refer to Literature Cited, p. 28.

82245—32——1

The results of the experiments with egg-destroying compounds in the laboratory are given as percentage of eggs dead. With larvicides, the results are given in terms of percentage of worms entering the fruit, percentage causing only stings, total percentage causing blemishes, and ratio of stings to total blemishes. The latter is used merely as a general indication of the relative value of the treatments. In the combination experiments with eggs and larvae, the percentage of worms entering the fruit is based on the total number of eggs in the experiment rather than on the total number of larvae hatching.

For the orchard experiments, plats containing from 12 to 75 trees were used. The spraying was done with a type of gasoline power sprayer commonly employed in commercial work. Spray guns and two lines of hose were used for most of the experiments. In some of the earlier work the pressure was kept at from 250 to 300 pounds at the pump; later, pressures of from 300 to 350 pounds were maintained.

Biological observations were made each season to determine the proper times for spraying. The same number of applications was given all the plats in any one year, but the number varied somewhat in different years, owing to variations in seasons and in the different orchards used. Ordinarily one calyx spray and four or five cover sprays were applied. In most of the experiments results were estimated by examining all of the fruit from 6 to 10 trees in the center of the plat. In a few cases, where small plats were used, the fruit from only two or four trees was examined.

The results of the orchard experiments are given, for the most part, in terms of percentage of fruit wormy, percentage of fruit stung, percentage of sound fruit, which is the fruit that is neither wormy nor stung, and ratio of stings to total blemishes; that is, to total entrances and stings. In the tables the two classes wormy and stung fruit will be found to overlap, as many apples having both types of injury will be counted in both classes. The percentage of wormy fruit is the most important criterion, but percentage of stung fruit is also important. This percentage is usually much lower when egg-destroying sprays are used than when the treatment consists only of larvicides, since few of the latter are able to kill the larva before it has started to feed. The percentage of sound fruit is a rather practical indication of the value of the treatment. A valuable guide also to the efficacy of the material used consists of a ratio. Melander (*4*) suggested using the ratio of worms to stings. In this bulletin it seems preferable to employ the ratio of stings to total blemishes. When strictly stomach poisons are used this ratio is higher for the more effective materials, as a larger percentage of larvae are killed after having fed long enough to produce a sting. In most cases comparison is made with a standard treatment of lead arsenate, 1 pound to 50 gallons, and also with an unsprayed check if one is available.

LEAD ARSENATE

The experiments with lead arsenate have included tests of lead-arsenate sprays of different strengths and tests of lead arsenate with spreaders and stickers.

One pound of powdered lead arsenate to 50 gallons of water has been used for many years and has become almost a standard dilution. The question is often raised whether a larger quantity would not produce results sufficiently better to warrant its use. In 1919 a field

test of lead arsenate at a dilution of 3 pounds to 50 gallons was made. The fruit used in this test turned out to be 3.2 per cent wormy, as compared with fruit 5.4 per cent wormy in a test of lead arsenate at a dilution of 1 pound to 50 gallons. There were more than twice as many stings and about twice as many calyx worms in the latter test as in the former. This indicated an advantage in the larger quantity of lead arsenate.

Laboratory experiments were then made in 1923 and 1924, the results of which have already been published (*5*, *Table 4*), but which are shown graphically by the solid line in Figure 1. These results

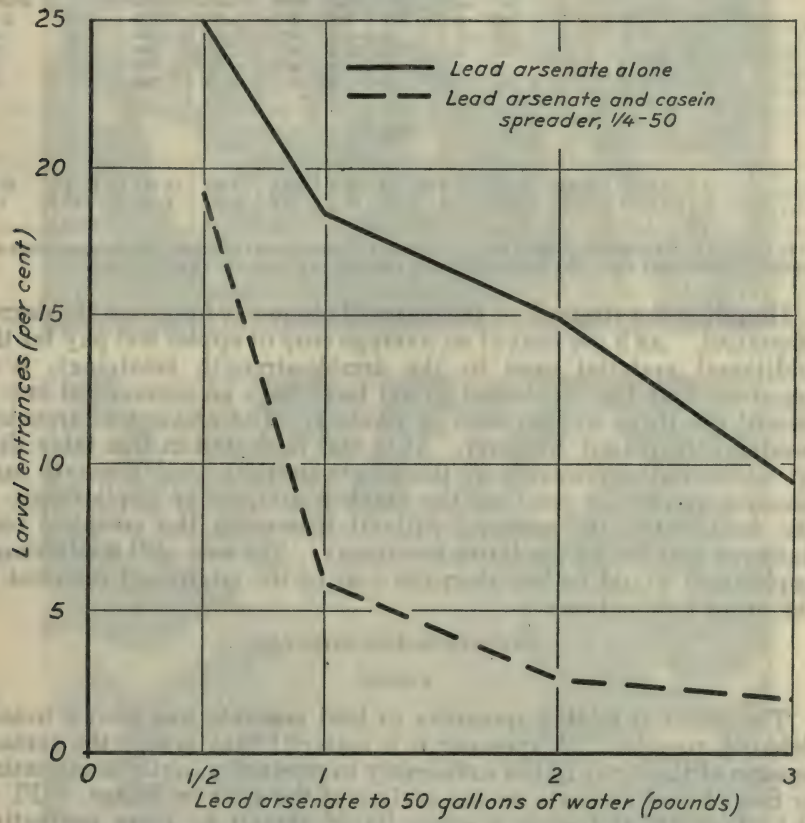


FIGURE 1.—The effect of lead arsenate at various dilutions, with and without casein spreader, on entrances of codling-moth larvae into fruit, Yakima, Wash., 1924

are a measure only of the freshly applied material, and show a very definite negative correlation between the degree of infestation and the strength of the lead arsenate.

Following these experiments orchard tests were made in 1927 and 1928. It was evident from the laboratory experiments that less than 1 pound of lead arsenate to 50 gallons would be ineffective, and, on account of the necessity of keeping the amount of arsenical residue at a minimum, there was no practical advantage in experimenting with more than 2 pounds to 50 gallons. Therefore, the orchard tests included only a comparison of 1 pound and 2 pounds of lead arsenate to 50 gallons of water. The results of these tests are shown in Table 1.

TABLE 1.—*Orchard experiments with lead arsenate for the codling moth, Yakima, Wash., 1927 and 1928*

Test No.	Applications	Dilution	Total apples	Wormy apples [1]		Stung apples [1]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes	Quantity of arsenic trioxide per pound of harvested fruit
	Number	*Pounds to gallons*	*Number*	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*		*Grain*
1927												
1	6	1 to 50	17,789	120	0.7	938	5.3	94.2	1,203	1,070	0.89	0.041
2	5	1 to 50	12,190	153	1.3	1,139	9.3	89.8	1,583	1,400	.88	.035
3	4	1 to 50	6,593	382	5.8	740	11.2	84.5	1,361	890	.65	.018
4	5	2 to 50	13,247	99	.7	589	4.4	95.0	798	689	.86	.044
5	4	2 to 50	11,236	195	1.7	788	7.0	91.7	1,176	948	.81	.033
1928												
6	7	1 to 50	30,645	3,531	11.5	10,142	33.1	62.2	24,581	18,911	0.77	0.026
7	7	2 to 50	22,710	1,192	5.2	5,599	24.7	72.6	10,569	8,770	.83	.044

[1] In this and in the succeeding tables that refer to orchard experiments all apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.

Doubling the strength of the material obviously improves the degree of control. As 3 per cent of an average crop of apples will pay for the additional material used in the double-strength treatment, it is apparent that this treatment would have been an economical one in two of the three comparisons in Table 1. The amount of arsenical residue is increased, however. It is also indicated in this table that an additional application of the single-strength lead arsenate may produce results as good as the smaller number of applications of the double-strength material without increasing the arsenical residue over that left by the latter treatment. The cost of this additional application would be less than the cost of the additional material in the other applications.

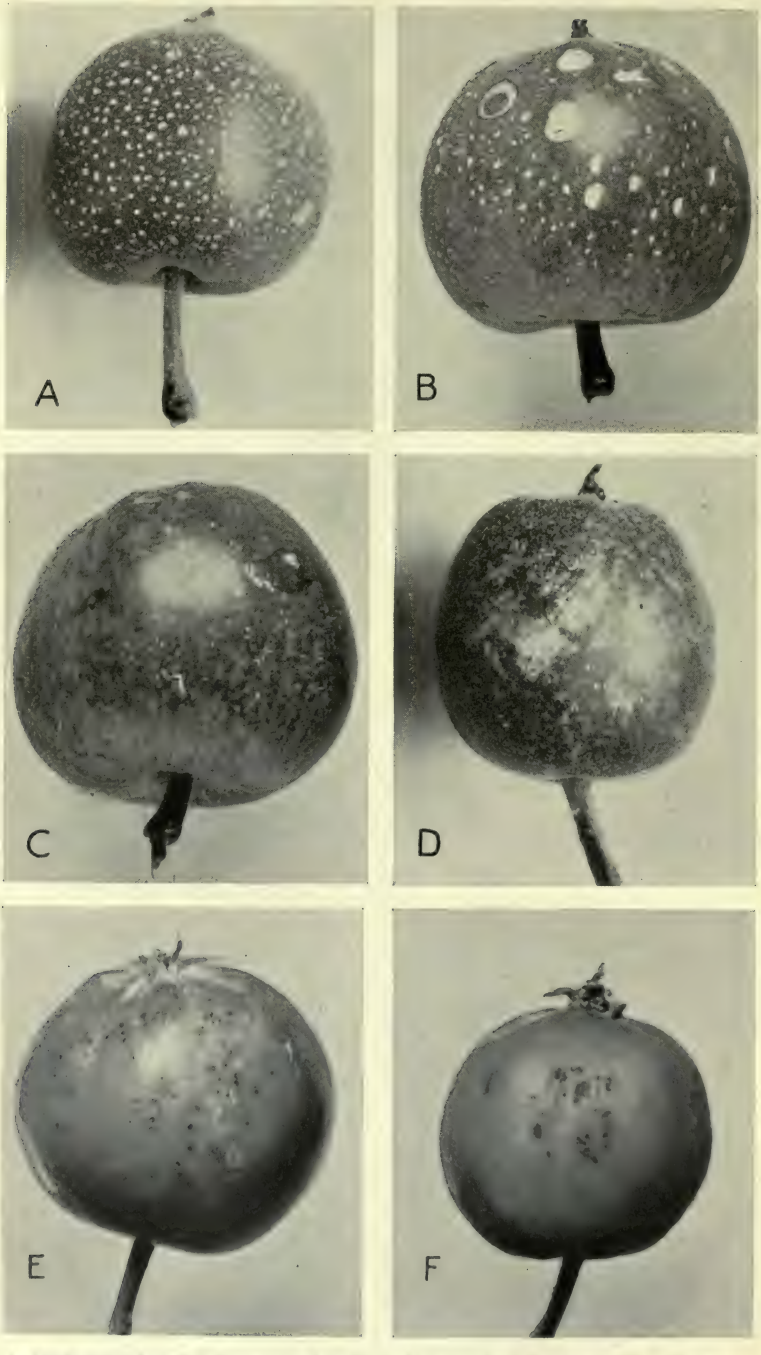
SPREADERS AND STICKERS

CASEIN

The value of adding spreaders to lead arsenate has been a much-debated question. A spreader is a material that lowers the surface tension of the spray liquid sufficiently to produce a continuous coating or film of lead arsenate on the surface of the fruit or foliage. (Pl. 1, B.) Theoretically, such a spray liquid should be more protective than one which contains no spreader and which forms droplets of irregular size on the surface with unprotected areas between. (Pl. 1, A, and 2, A.) Smith (*7*) did not get very much better results with the film type of coverage when he used a casein spreader containing 25 per cent casein and 75 per cent calcium hydrate in the proportion of 1 pound to 100 gallons of liquid than with the spotted type. In experiments made by the senior writer in 1923 and 1924 with the same material the results were similar to Smith's when the same proportion of spreader was used (*5, Table 2*). (Fig. 2.) The writers are in accord with Smith's conclusions that this may have been due primarily to a coating of poison that was thinner but that was also smoother and more adherent, giving the larva less opportunity for accumulating

TYPES OF SPRAY DEPOSIT

A, Apple sprayed with lead arsenate alone; B, apple sprayed with lead arsenate to which casein spreader has been added.



A, Apple sprayed with lead arsenate alone; B, lead arsenate and flour paste; C, lead arsenate and soap; D, lead arsenate and glue; E, apple burned by nicotine oleate; F, apple burned by derris extract

particles of poison before beginning to feed. Spuler (*8, p. 31*) got slightly better results with lead arsenate alone than with lead arsenate and casein spreader, but he shows that the difference is too small to be significant. In a letter Mr. Spuler stated that the casein spreader was used in the proportion of 1 pound to 200 gallons.

In the writers' experiments it was found that there was a positive correlation between the quantity of spreader used and the degree of infestation. (Fig. 2.) In order to explain the increased protection afforded by decreasing the quantity of spreader used, it is reasonable to assume that the larger quantity of spreader causes a greater run-off and consequently results in a thinner coat of lead arsenate on the fruit. This assumption has not yet been proved, and the facts in regard to the experiments are given here as an indication of some such cause. Reference to the senior writer's previous publication on this subject (*5*) will show that these results were obtained in two

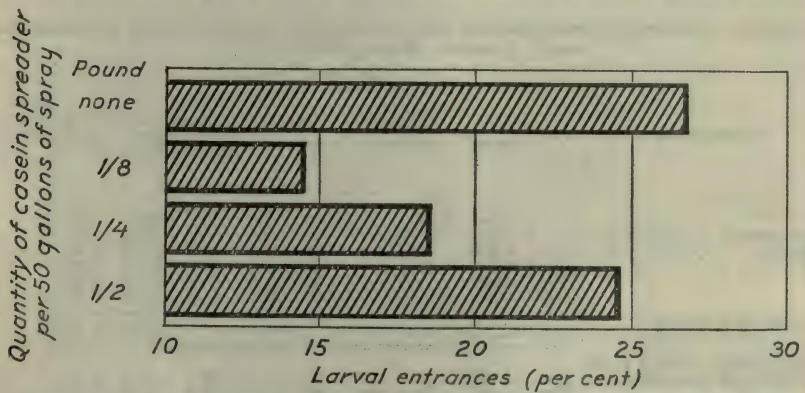


FIGURE 2.—Effect of quantity of spreader used with lead arsenate on larval entrances of the codling moth, Yakima, Wash., 1924

successive years. Similar results were obtained in 1925 and 1926, the only exception being in test 6. (Table 2.)

TABLE 2.—*Laboratory experiments with lead arsenate and casein spreader on the larvae of the codling moth, Yakima, Wash., 1925 and 1926*

Test No.	Material used [1]	Worms entering fruit		Worms causing stings		Total blemishes	Ratio of stings to total blemishes
		Number	*Per cent*	*Number*	*Per cent*	*Per cent*	
	1925						
1	Lead arsenate, 1–50, no spreader	35	10.0	77	22.0	32.0	0.69
2	Lead arsenate, 1–50, casein spreader 1/8–50	7	3.5	27	13.5	17.0	.79
3	Lead arsenate, 1–50, casein spreader 1/4–50	9	4.5	31	15.5	20.0	.78
4	Check (unsprayed)	121	40.3	55	18.3	58.6	.31
	1926						
5	Lead arsenate, 1–50, no spreader	12	8.0	33	22.0	30.0	0.73
6	Lead arsenate, 1–50, casein spreader 1/16–50	16	10.7	30	20.0	30.7	.65
7	Lead arsenate, 1–50, casein spreader 1/2–50	13	8.7	21	14.0	22.7	.62
8	Lead arsenate, 2–50, no spreader	7	4.7	29	19.3	24.0	.81
9	Lead arsenate, 2–50, casein spreader 1/16–50	3	2.0	31	20.7	22.7	.91
10	Lead arsenate, 2–50, casein spreader 1/2–50	4	2.7	33	22.0	24.7	.89
11	Check (unsprayed)	80	53.3	10	6.7	60.0	.11

[1] Proportions, pounds to gallons.

This laboratory work merely shows the effect of the addition of casein spreader when the spray has been freshly applied. It is necessary to carry these experiments to the orchard to find out whether the use of casein spreader has any practical value. Such experiments were made in four different years, 4 or 5 ounces of casein being used to 200 gallons of spray, the casein being dissolved in water by means of borax, sodium bicarbonate, or calcium hydrate. The results of the use of lead arsenate alone and with casein spreader are very similar, whether a comparison is made of the percentage of wormy, stung, or sound fruit, or of the ratio of stings to total blemishes. (Table 3.) There is generally a consistent slight difference in favor of the lead arsenate and spreader, but this is so slight that it can not be said that the addition of 4 or 5 ounces of casein to 200 gallons of spray is of any benefit other than in preventing blotching of the fruit.

TABLE 3.—*Orchard experiments with lead arsenate and casein spreader for the codling moth, Yakima, Wash., 1919–1923*

Material used	Year	Total apples	Wormy apples [1]		Stung apples [1]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes
		Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
Lead arsenate, 1 pound to 50 gallons	1919	13,968	749	5.4	1,926	13.8	82.5	3,516	2,643	0.75
	1921	23,217	781	3.4	1,868	8.0	89.2	3,177	2,303	.72
	1922	15,021	1,634	10.9	4,858	32.3	62.6	11,743	9,623	.82
	1923	6,276	485	7.7	1,324	21.1	74.2	2,672	1,987	.74
Total or average				[2] 6.9		[2] 18.8	[2] 77.1	21,108	16,556	[3] .78
Lead arsenate, 1 pound to 50 gallons, plus casein spreader	1919	15,987	533	3.3	1,400	8.8	88.7	2,358	1,750	.74
	1921	19,670	518	2.6	1,266	6.4	91.3	2,117	1,537	.73
	1922	9,721	1,008	10.4	3,018	31.0	64.2	6,980	5,718	.82
	1923	6,546	420	6.4	1,746	26.7	69.9	3,305	2,753	.83
Total or average				[2] 5.7		[2] 18.3	[2] 78.5	14,760	11,758	[3] .80
Check (unsprayed)	1919	9,608	5,524	57.5	1,132	11.8	39.3	13,043	1,421	.11
	1921	25,512	10,710	42.0	1,891	7.4	56.3	25,720	2,327	.09
	1922	6,084	3,927	64.5	460	7.6	34.5	10,957	542	.05
	1923	3,621	2,537	70.1	290	8.0	27.8	7,317	331	.05
Total or average				[2] 58.6		[2] 8.7	[2] 39.5	57,037	4,621	[3] .08

[1] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.
[2] Simple average.
[3] Percentage of total.

The quantity of casein used in these experiments is approximately what occurs in 1 pound of casein spreader. Therefore, these results are similar to those obtained in the laboratory with one-fourth pound of casein spreader to 50 gallons of spray. (Fig. 2.) In 1928 an orchard experiment was made in which only one-half pound of casein spreader to 200 gallons of spray was used. In this experiment the fruit sprayed with lead arsenate alone became wormier than that sprayed with lead arsenate and casein spreader, indicating an advantage in the smaller amount of spreader. The detailed results are shown in Table 4.

TABLE 4.—*Results of application of lead arsenate with and without spreader in orchard tests for the control of the codling moth, Yakima, Wash., 1928*

Test No.	Material used	Total apples	Wormy apples		Stung apples [1]		Sound apple	Total blemishes	Total stings	Ratio of stings to total blemishes
		Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
1	Lead arsenate, 1 pound to 50 gallons	20,026	418	2.1	637	3.2	95.2	1,318	786	0.60
2	Lead arsenate, 1 pound, plus casein spreader, ¼ pound, to 50 gallons	21,782	303	1.4	569	2.6	96.3	1,029	675	.66

[1] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.

FISH OIL

Fish oil has been used successfully by Hood (*2*) as a sticker for lead arsenate to keep the latter from being washed from foliage by heavy rains. Although rains are infrequent in the arid regions of Washington, better adherence of the lead arsenate was considered desirable, and some experiments with a salmon oil were made. Spuler (*8, p. 33*) had obtained definitely better results with the addition of fish oil in field tests in 1927. The writers tested this material both in the laboratory and in the orchard in 1928. In the laboratory, when 1 pound of lead arsenate was used to 50 gallons of water, and fish oil in the proportion of one-half pint to 50 gallons, 10.7 per cent of the larvae entered the fruit as compared with 20.0 per cent when the lead arsenate was used alone.

In the orchard test an attempt was made to show whether the addition of fish oil to the lead arsenate would make it possible to discontinue spraying at an earlier date than if the fish oil were not used. Therefore, the plat on which the fish oil was used was not sprayed after the fourth application, although three more applications were made to the trees receiving lead arsenate alone. In other words, the fish-oil plat was sprayed only for the first brood of codling-moth larvae. This was done because it had been found that the use of fish oil with lead arsenate made the removal of the arsenical residue from the mature fruit very difficult. As shown in Table 5, better results were obtained with seven applications of lead arsenate alone than with four of lead arsenate and fish oil, although the difference is not so great as would be expected if no fish oil had been used, judging from the results obtained with only two applications of lead arsenate. It is evident that fish oil could be used to obtain better control of the codling moth if it were not for the subsequent difficulty of removing the residue.

TABLE 5.—*Orchard experiments with lead arsenate and fish oil for the codling moth, Yakima, Wash., 1928*

Test No.	Material used	Total apples	Wormy apples[1]		Stung apples[1]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes
			Number	Per cent	Number	Per cent	Per cent	Number	Number	
1	Lead arsenate, 1 pound to 50 gallons; 7 sprays	11,144	704	6.3	2,353	21.1	75.1	4,199	3,258	0.78
2	Lead arsenate, 1 pound to 50 gallons; first 2 sprays only	5,444	2,108	38.7	1,538	28.3	49.5	7,741	2,531	.33
3	Lead arsenate, 1 pound to 50 gallons, plus fish oil, ⅛ per cent; first 4 sprays only	11,701	2,242	19.2	3,014	25.8	62.2	7,837	4,475	.57

[1] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.

OTHER SPREADERS

Experiments were also made with other materials including glue, flour paste, and soap. The glue was added to the lead-arsenate spray in the proportions of one-fourth pound and one-half pound to 100 gallons, flour paste was used in the proportion of 1½ pounds to 100 gallons, and linseed oil and fish oil soap were used at the rate of 1½ and 4 pounds to 100 gallons, respectively. It is unnecessary to present detailed results of these experiments, but the percentages of wormy apples are given in Table 6.

TABLE 6.—*Experiments with glue, flour paste, and soap added as stickers to lead arsenate for the control of the codling moth, Yakima, Wash., 1920–1922*

Material used	Percentages of wormy apples in—		
	1920	1921	1922
Lead arsenate	4.2	3.4	18.5
Lead arsenate plus glue	5.2	5.3	----------
Lead arsenate plus flour paste	----------	16.0	31.8
Lead arsenate plus soap	8.6	----------	29.6

The results with the flour paste and the soap were decidedly unsatisfactory. The paste dried, cracked, and peeled off, taking much of the lead arsenate with it (pl. 2, B), and the soap apparently left too thin a coating of poison on the apples. (Pl. 2, C.) Only the glue (pl. 2, D) gave results approaching those obtained from the lead arsenate alone, but it is apparent that there is no advantage in adding the glue.

OTHER ARSENICALS

In 1927 a number of nonlead arsenicals were tested with the hope of finding something that might replace lead arsenate. Although some of these had previously been found to be inferior, it was thought that improvements might have been made by new methods of manufacture. In the laboratory experiments were made with 11 arsenates and 2 arsenites, in comparison with lead arsenate, at dilutions of 1 pound and 2 pounds to 50 gallons. The results of these experiments are detailed in Table 7.

TABLE 7.—*Laboratory experiments with nonlead arsenicals for the larvae of the codling moth, Yakima, Wash., 1927*

Test No.	Material used	Worms entering fruit		Worms causing stings		Total blemishes	Ratio of stings to total blemishes
		Number	*Per cent*	*Number*	*Per cent*	*Per cent*	
	DILUTED, 1 POUND TO 50 GALLONS						
1	Lead arsenate	50	33.3	20	13.3	46.6	0.29
2	Calcium arsenate (A)	75	50.0	5	3.3	53.3	.06
3	Calcium arsenate (B)	70	46.7	17	11.3	58.0	.20
4	Tricalcium arsenate	63	42.0	13	8.7	50.7	.17
5	Aluminum arsenate	86	57.3	4	2.7	60.0	.04
6	Barium arsenate	53	35.3	19	12.7	48.0	.26
7	Ferric arsenate	87	58.0	5	3.3	61.3	.05
8	Zinc arsenate	54	36.0	19	12.7	48.7	.26
9	Copper arsenate	72	48.0	1	.7	48.7	.01
10	Titanium arsenate	86	57.3	1	.7	58.0	.01
11	Magnesium arsenate	91	60.7	6	4.0	64.7	.06
12	Manganese arsenate	54	36.0	19	12.7	48.7	.26
13	Check (unsprayed)	116	77.3	0	0.0	77.3	.00
27	Lead arsenate	45	30.0	21	14.0	44.0	.32
28	Calcium arsenite	70	46.7	10	6.7	53.3	.13
29	Zinc arsenite	62	41.3	12	8.0	49.3	.16
30	Check (unsprayed)	109	72.7	3	2.0	74.7	.03
	DILUTED, 2 POUNDS TO 50 GALLONS						
14	Lead arsenate	28	28.0	7	7.0	35.0	0.20
15	Calcium arsenate (A)	32	32.0	2	2.0	34.0	.06
16	Calcium arsenate (B)	46	46.0	4	4.0	50.0	.08
17	Tricalcium arsenate	36	36.0	5	5.0	41.0	.12
18	Aluminum arsenate	56	56.0	2	2.0	58.0	.03
19	Barium arsenate	35	35.0	4	4.0	39.0	.10
20	Ferric arsenate	45	45.0	0	0.0	45.0	.00
21	Zinc arsenate	22	22.0	13	13.0	35.0	.37
22	Copper arsenate	39	39.0	3	3.0	42.0	.07
23	Titanium arsenate	59	59.0	0	0.0	59.0	.00
24	Magnesium arsenate	56	56.0	2	2.0	58.0	.03
25	Manganese arsenate	39	39.0	2	2.0	41.0	.05
26	Check (unsprayed)	80	80.0	0	0.0	80.0	.00
31	Lead arsenate	28	28.0	8	8.0	36.0	.22
32	Calcium arsenite	30	30.0	4	4.0	34.0	.12
33	Zinc arsenite	22	22.0	12	12.0	34.0	.35
34	Check (unsprayed)	76	76.0	0	0.0	76.0	.00

None of the arsenates tried equaled lead arsenate in these tests. The barium, zinc, and manganese arsenates were the best, considering both dilutions. The two arsenites, at double strength, were also good.

All of these materials, with the exception of the copper and titanium arsenates and the calcium arsenite, were tested in the orchard, and, as shown in Table 8, none of them gave as good control as lead arsenate.

Some very interesting information on the injury caused by these arsenicals was obtained from the orchard plats of 1927. The rainfall in September was unusually heavy, and, although the precipitation for the month was only about an inch, it was distributed over the first third of the month, and was accompanied by cloudy, moist weather. Soon after this injury began to appear in most of the plats on both fruit and foliage. A little was found even in the lead-arsenate plat, although usually lead arsenate does not cause any noticeable injury. Injury to the fruit consisted chiefly of sunken black areas about the calyx end where the greatest quantity of arsenical collected (pl. 3, A); foliage injury took the form of a typical arsenical burn appearing in patches of various sizes. (Pl. 3, B.)

TABLE 8.—*Orchard experiments with nonlead arsenicals for the codling moth, Yakima, Wash., 1927*

Test No.	Material used	Quantity used per 50 gallons [1]	Total apples	Wormy apples [2]		Stung apples [2]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes	Quantity of arsenic trioxide per pound of harvested fruit [3]
		Lbs.	*Number*	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*		*Grain*
1	Lead arsenate	1.00	17,789	120	0.7	938	5.3	94.2	1,203	1,070	0.89	0.041
2	Calcium arsenate (A)	.76	2,840	136	4.8	487	17.1	80.2	957	787	.82	.025
3	Calcium arsenate (B)	1.00	2,523	111	4.4	394	15.6	81.3	721	584	.81	.030
4	Tricalcium arsenate	.76	2,560	160	6.3	509	19.9	76.7	954	739	.77	.025
5	Aluminum arsenate	.88	1,986	238	12.0	461	23.2	69.1	1,052	707	.67	.029
6	Barium arsenate	1.00	2,446	172	7.0	588	24.0	72.8	1,128	880	.78	.043
7	Ferric arsenate	1.57	1,489	282	18.9	317	21.3	67.6	936	502	.54	.025
8	Zinc arsenate	.88	2,307	112	4.9	343	14.9	82.2	598	456	.76	.067
9	Magnesium arsenate	1.00	2,635	467	17.7	587	22.3	67.7	1,526	877	.57	.077
10	Manganese arsenate	.76	1,985	59	3.0	270	13.6	84.7	420	346	.82	.044
11	Zinc arsenite	.75	2,117	73	3.4	391	18.5	79.4	643	545	.85	.080
12	Check	-------	1,843	679	36.8	486	26.4	49.5	1,823	730	.40	----------

[1] Quantity of each material used contained amount of As_2O_5 equal to that in 1 pound of lead arsenate, except that ferric arsenate was used at double strength.

[2] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.

[3] Analyses by J. C. Palmer, Food and Drug Administration.

The injury to the fruit was determined by actual count, and the leaf injury was estimated on October 18 by carefully examining the trees in each plat. A determination was also made of the percentage of water-soluble arsenic in the total quantity of arsenic present on the leaves from most of the plats. These determinations are given in Table 9, along with a statement of the water-soluble arsenic in the original arsenicals. Injury to the fruit occurred only in the aluminum arsenate and zinc-arsenite plats, but foliage injury was found in all of the plats. There was no positive correlation between the degree of injury and the percentage of water-soluble arsenic in the arsenicals. Both ferric arsenate and aluminum arsenate, with high original water-soluble arsenic content, produced relatively little foliage injury, whereas several materials originally free of water-soluble arsenic, or nearly so, caused severe burning. The degree of injury is more nearly correlated with the percentage of water-soluble arsenic found on the leaves after the injury occurred. These results suggest that some of these materials were less stable than others, and that consequently varying quantities of water-soluble arsenic were formed after the spraying was done, without regard to the original water-soluble content.

The poor control obtained with these nonlead arsenicals and the relatively high degree of injury resulting from their use practically eliminated all of them from consideration. However, experiments with two of these materials were continued in 1928. The aluminum arsenate was tested at double strength with one-eighth of 1 per cent fish oil in an effort to make it adhere better; and the zinc arsenate was also used at double strength, with the addition of an equal amount of hydrated lime for the purpose of preventing injury. When used in this manner, in laboratory tests, these materials were not so effective as single-strength lead arsenate (Table 10), the aluminum arsenate being the poorer of the two. In an orchard test, under

very wormy conditions, the use of aluminum arsenate resulted in nearly twice as much wormy fruit as when lead arsenate was used, and spraying with zinc arsenate resulted in 50 per cent more wormy fruit than spraying with lead arsenate. (Table 11.) This was in spite of the apparent adherence of a greater quantity of the aluminum arsenate and zinc arsenate to the fruit than of the lead arsenate, the number of grains per pound of harvested fruit being 0.043, 0.044, and 0.036, respectively.[3] No injury occurred in 1928.

TABLE 9.—*Injury to apple fruit and foliage from applications of nonlead arsenicals, Yakima, Wash., 1927*

Test No.	Material used	Water-soluble arsenic pentoxide in original material [1]	Fruit injured [2]	Leaves dropped Oct. 18 [3]	Leaves injured (of those remaining) [3]	Percentage of the arsenic trioxide on the leaves that was water-soluble [4]
		Per cent	*Per cent*	*Per cent*	*Per cent*	
1	Lead arsenate	0.12	0	0	1	0.007
2	Calcium arsenate (A)	Free.	0	0	30	.029
3	Calcium arsenate (B)	do.	0	1	65	.051
4	Tricalcium arsenate	do.	0	0	80	
5	Aluminum arsenate	3.80	7.1	0	10	.016
6	Barium arsenate	.16	0	0	80	
7	Ferric arsenate [5]	2.86	0	0	2	.038
8	Zinc arsenate	.16	0	15	50	
9	Magnesium arsenate	.23	0	0	5	
10	Manganese arsenate	.50	0	0	10	.031
11	Zinc arsenite	.03	42.3	40	90	.142

[1] As given by manufacturer.
[2] By actual count.
[3] Estimated.
[4] Analyses by C. D. Dolman, chemist, State of Washington Division of Horticulture.
[5] Double strength.

TABLE 10.—*Laboratory experiments with nonlead arsenicals on the larvae of the codling moth, Yakima, Wash., 1928*

Test No.	Material used [a]	Worms entering fruit		Worms causing stings		Total blemishes	Ratio of stings to total blemishes
		Number	*Per cent*	*Number*	*Per cent*	*Per cent*	
1	Lead arsenate 1–50	30	20.0	31	20.7	40.7	0.51
2	Aluminum arsenate 2–50, fish oil, 1 quart–200 gallons	65	43.3	15	10.0	53.3	.19
3	Zinc arsenate 2–50, lime 2 pounds	40	26.7	25	16.7	43.4	.38
4	Check (unsprayed)	81	54.0	9	6.0	60.0	.10

[a] Proportions, with exception of fish oil, are pounds to gallons.

[3] Analyses by C. R. Gross, Bureau of Chemistry and Soils.

TABLE 11.—*Orchard experiments with nonlead arsenicals for the codling moth, Yakima, Wash., 1928*

Test No.	Material used [1]	Total apples	Wormy apples [2]		Stung apples [2]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes
		Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
1	Lead arsenate 1-50	5,502	1,251	22.7	1,333	24.2	60.1	3,639	1,780	0.49
2	Aluminum arsenate 2-50, fish oil, 1 quart to 200 gallons in first four sprays	2,738	1,151	42.0	631	23.1	46.1	2,636	802	.30
3	Zinc arsenate 2-50, lime 2 pounds	3,516	1,161	33.0	680	19.3	55.0	2,517	811	.32

[1] Proportions, excepting fish oil, are pounds to gallons.
[2] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.

LUBRICATING OILS

LABORATORY EXPERIMENTS

Mineral oils of the lubricating type were first thought of in connection with codling-moth control as egg destroyers. Laboratory experiments were made from 1923 to 1927 primarily to determine the percentage of codling-moth eggs that would fail to hatch when sprayed with an oil emulsion. Other experiments were made to determine the effect on eggs deposited after spraying, as well as the influence on the oviposition of the moths.

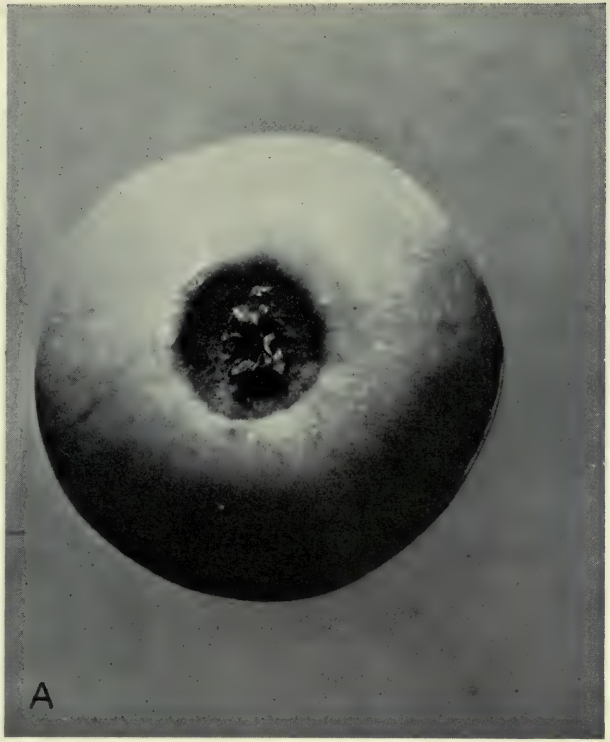
EFFECT OF OIL SPRAYS APPLIED TO THE EGGS

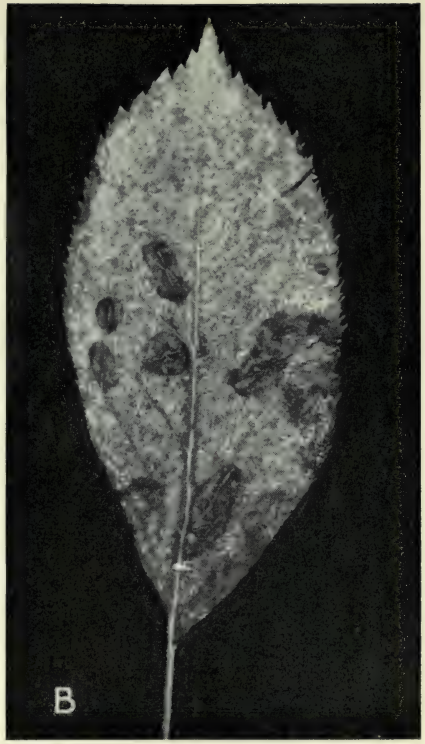
In a preliminary test in 1923 with an emulsion of red engine oil,[4] 75 per cent of the eggs sprayed with 1 per cent oil failed to hatch, and 97.6 per cent of those sprayed with 2 per cent oil failed to hatch, as compared with 26 per cent of the unsprayed eggs. In 1924, 1925, and 1926 more extensive experiments were made with various oils, such as red engine,[4] brown neutral [5] and crystal [6] oils. The effect of these oils was similar, except that the heavier oils caused a somewhat higher mortality of eggs than the lighter ones. In order to show these effects the results of some tests of a medium oil are given in Table 12. Apparently a high mortality can be obtained with less than 1 per cent of oil. The addition of casein spreader or lead arsenate, as in tests 10 and 11, lowered the effectiveness of the spray, probably because these materials absorbed some of the oil.

In 1927 tests were made with more highly refined oils of the types now employed in commercial-oil emulsions intended for summer spraying. The relatively light mineral seal oil destroyed fewer eggs than the less highly refined oils previously tested, while the heavy oil resulted in a complete mortality. There was little difference between the oil emulsion and the miscible oil. (Table 12.)

In many of these tests, eggs of different ages were used, ranging from eggs less than a day old to those almost ready to hatch. If the data from 15 experiments, representing over 8,000 eggs, are arranged according to the interval between oviposition and spraying, a definite negative correlation is found to exist between the interval and the percentage failing to hatch. (Fig. 3.)

[4] No. 1 (see p. 27). [5] No. 2. [6] No. 3.





INJURY BY ZINC ARSENITE SPRAY

A, To fruit; B, to foliage.

TABLE 12.—*Laboratory experiments with lubricating-oil sprays on the eggs of the codling moth, Yakima, Wash., 1924 and 1927*

1924

Test No.	Material used	Dilution of oil	Total eggs	Eggs dead	
		Per cent	*Number*	*Number*	*Per cent*
1	Lubricating-oil [1] emulsion (casein-lime emulsifier)	2	312	311	99.7
2	do	1	545	525	96.3
3	do	.67	340	327	96.2
4	Check		495	73	14.7
5	Lubricating-oil [1] emulsion (casein- lime emulsifier)	1	422	395	93.6
6	do	.67	476	428	89.9
7	do	.5	519	384	74.0
8	Check		637	111	17.4
9	Lubricating-oil [1] emulsion (casein-lime emulsifier)	.67	415	362	87.2
10	Material used in test 9, plus casein spreader 1 to 200 [2]	.67	436	328	75.2
11	Materials used in test 10, plus lead arsenate 1 to 50 [2]	.67	202	121	59.9
12	Check		33	1	3.0

1927

1	Lubricating-oil [3] emulsion (casein-lime emulsifier)	1.5	71	63	88.7
2	do	.75	81	58	71.6
3	Miscible oil [3]	1.5	106	90	84.9
4	do	.75	154	104	67.5
5	Lubricating-oil [4] emulsion (casein-lime emulsifier)	1.5	101	101	100.0
6	do	.75	111	111	100.0
7	Miscible oil [4]	1.5	65	65	100.0
8	do	.75	160	160	100.0
9	Check		611	98	16.0

[1] Brown neutral oil, No. 2 (see p. 27).
[2] Pounds to gallons.
[3] Mineral seal oil No. 4 (see p. 27).
[4] Technical oil No. 5.

THE EFFECT ON EGGS DEPOSITED AFTER SPRAYING

The first experiments on the effect of oil emulsions on eggs deposited after spraying were made in 1924. Pear leaves were sprayed with an emulsion containing 1 per cent of red engine oil,[7] and equal numbers of sprayed and unsprayed leaves were placed before the moths in oviposition jars at intervals of from a few hours to eight days after spraying, each lot being left in the jars 24 hours. The mortality of eggs deposited on the sprayed leaves was high for the first three days, and considerably lower after that, as is shown in Table 13.

TABLE 13.—*Effect of oil emulsion covering foliage on codling-moth eggs laid at various intervals after spraying, Yakima, Wash., 1924*

Interval between spraying and deposition of eggs	Total eggs	Eggs dead		Interval between spraying and deposition of eggs	Total eggs	Eggs dead	
	Number	*Number*	*Per cent*		*Number*	*Number*	*Per cent*
0 [1] days	980	924	94.3	4 days	805	534	66.3
1 day	962	760	79.0	8 days	203	127	62.6
2 days	815	736	90.3	Check	3,219	850	26.4
3 days	784	720	91.8				

[1] Eggs deposited a few hours after spraying.

It was thought that the use of leaves might not give a fair test, because of drying during the course of the experiment, so in 1926

[7] No. 1 (see p. 27).

apples were sprayed with emulsions containing 1 and 2 per cent of heavy crystal[8] oil. The first test was made in May, eggs being deposited within two days after spraying. With the 2 per cent oil, of 461 eggs sprayed, 87 per cent failed to hatch; with the 1 per cent oil, of 137 eggs, 73 per cent failed to hatch; and in a check sprayed with lead arsenate, of 429 eggs, 26.3 per cent failed to hatch. In August, when the weather was warmer, another test was made, and it was found that the 2 per cent oil was much more effective than the 1 per cent, and the percentage of eggs failing to hatch decreased as the interval between spraying and deposition increased. This is shown in Table 14.

TABLE 14.—*Effect of crystal oil emulsion covering apples on codling-moth eggs laid at various intervals after spraying, Yakima, Wash., August, 1926*

Interval between spraying and deposition of eggs	1 per cent crystal oil			2 per cent crystal oil		
	Total eggs	Eggs dead		Total eggs	Eggs dead	
	Number	*Number*	*Per cent*	*Number*	*Number*	*Per cent*
3 days	44	16	36.4	80	64	80.0
5 days	92	30	32.6	191	136	71.2
7 days	263	100	38.0	54	35	64.8
9 days	265	69	26.0	26	12	46.2
Check				392	46	11.7

Similar tests were made in 1927, both the heavy crystal oil and the light mineral seal oil being used. In spite of some discrepancies that appear in Table 15, it is evident that only a relatively low percentage of eggs are killed, when deposited on oil-sprayed surfaces, unless a heavy oil is used and the deposition occurs within a few days after spraying.

TABLE 15—*Effect of various oil emulsions covering apples on codling-moth eggs laid at various intervals after spraying, Yakima, Wash., 1927*

Interval between spraying and deposition of eggs	Eggs dead (per cent) following use of—				Average
	Mineral seal oil		Crystal oil		
	¾ per cent	1½ per cent	¾ per cent	1½ per cent	
3 days	26.4	34.7	36.6	58.0	43.0
6 days	12.2	11.7	2.7	48.1	16.9
9 days	39.2	13.7	17.1	76.7	35.4
Average	28.8	21.4	21.9	60.9	33.5
Check					4.2

THE EFFECT OF AN OIL DEPOSIT ON OVIPOSITION

Experiments were also made to determine what effect spraying with oil might have on oviposition. In other words, would the presence of an oil spray on leaves and fruit deter the moths from depositing eggs?

In May, 1924, fresh pear leaves were throughly sprayed with an emulsion containing 1 per cent of red engine[9] oil. Equal numbers

[8] No. 3 (see p. 27). [9] No. 1 (see p. 27).

of sprayed and unsprayed leaves were placed with the moths in oviposition jars within two days after spraying. Of 5,693 eggs deposited on these leaves, 3,210, or 56.4 per cent, were deposited on the oil-sprayed leaves.

In May, 1926, apples and leaves from oil-sprayed trees were placed in oviposition jars within two days after spraying. In one test material sprayed with an emulsion containing 1 per cent of a heavy crystal oil [10] was compared with material sprayed with lead arsenate. Of 204 eggs, 76.5 per cent were deposited on the oil-sprayed leaves and fruit. In another test 2 per cent oil was compared with lead arsenate, and of 1,287 eggs, 45.7 per cent were deposited on the oil-sprayed material. In a third test, comparing the 2 per cent oil with the 1 per cent oil, of 161 eggs, 55.3 per cent were on the material sprayed with the 2 per cent oil.

In June, 1926, fresh pear leaves were thoroughly sprayed with emulsions containing 1 and 2 per cent of crystal oil, respectively. Leaves from each lot were placed in oviposition jars with equal quantities of unsprayed leaves within three days after spraying. In the test comparing the 1 per cent oil-sprayed leaves with unsprayed leaves, of 1,277 eggs, 45.7 per cent were deposited on the oil-sprayed leaves. In the test of 2 per cent oil, of 1,565 eggs, 37.4 per cent were deposited on the oil-sprayed leaves.

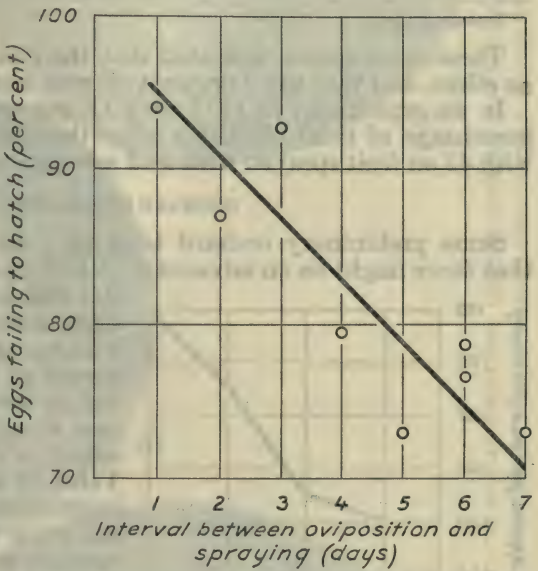


FIGURE 3.—Percentage of mortality in codling-moth eggs sprayed with an oil emulsion at various numbers of days after date of oviposition, Yakima, Wash., 1926 and 1927

The conclusion to be drawn from these experiments is that, under laboratory conditions, the oil does not especially deter the codling moth from ovipositing. Orchard trees sprayed with oil emulsion alone become wormier than those sprayed with lead arsenate alone, and it may be inferred from this and from the results of these laboratory experiments that spraying with oil will not particularly reduce the number of eggs deposited.

THE EFFECT OF AN OIL DEPOSIT ON LARVAL ENTRANCE

In order to find out whether the oil sprays prevented larvae from entering apples an experiment was made in 1926, a crystal oil [11] emulsion being used at dilutions of 1 and 2 per cent and worms placed on the fruit at intervals after spraying. Table 16 shows the number of larvae that succeeded in entering the fruit and the number making stings only.

[10] No. 3 (see p. 27).

[11] No. 3 (see p. 27).

TABLE 16.—*Record of larval attacks on apples sprayed with oil emulsion and with lead arsenate, Yakima, Wash., 1926*

Material used	Interval after spraying	Larvae entering fruit	Larvae making stings	Total blemishes
	Days	*Per cent*	*Per cent*	*Per cent*
1 per cent crystal oil	4	62	2	64
	6	64	4	68
	8	48	2	50
	10	58	4	62
	12	68	0	68
2 per cent crystal oil	2	26	2	28
	4	38	12	50
	6	36	4	40
	8	66	0	66
	10	52	4	56
Lead arsenate, 1 pound to 50 gallons [1]		19	16	35
Check (unsprayed) [1]		63	1	64

[1] Average of 2 tests.

These experiments indicated that the 1 per cent oil had practically no effect, and that the 2 per cent oil was ineffective after a few days.

In an experiment in 1927 with 1½ per cent mineral seal oil,[12] the percentage of total blemishes after three days was 72, as compared with 42 on fruit sprayed with lead arsenate and 74 on unsprayed fruit.

ORCHARD EXPERIMENTS

Some preliminary orchard tests in 1924 and 1925 had indicated that there might be an advantage in adding an oil emulsion to some of the lead-arsenate applications. In 1926, therefore, a test was made in which a calyx spray and five cover sprays of lead arsenate were used, and in certain plats 1, 2, and 4 per cent technical oil, respectively, was added in the form of an emulsion. Table 17 shows that a very definite improvement in control resulted in the plats where oil was used, the percentage of both wormy and stung apples decreasing as the percentage of oil was increased. However, considerable injury resulted from the use of this heavy oil. The oil reduced the size of the fruit, the number of apples per box increasing as the amount of oil increased. (Fig. 4.) In the Rome Beauty variety a very decided darkening of the area about the calyx was caused by the oil. (Pl. 4, A.) Other varieties were injured in various ways, the Jonathan, for example, developing irregular brown spots (pl. 4, B), and the Yellow Newtown becoming russetted about the calyx end. (Pl. 4, C.)

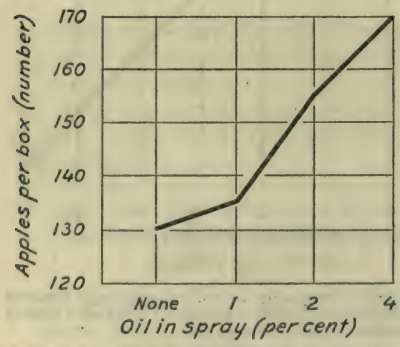
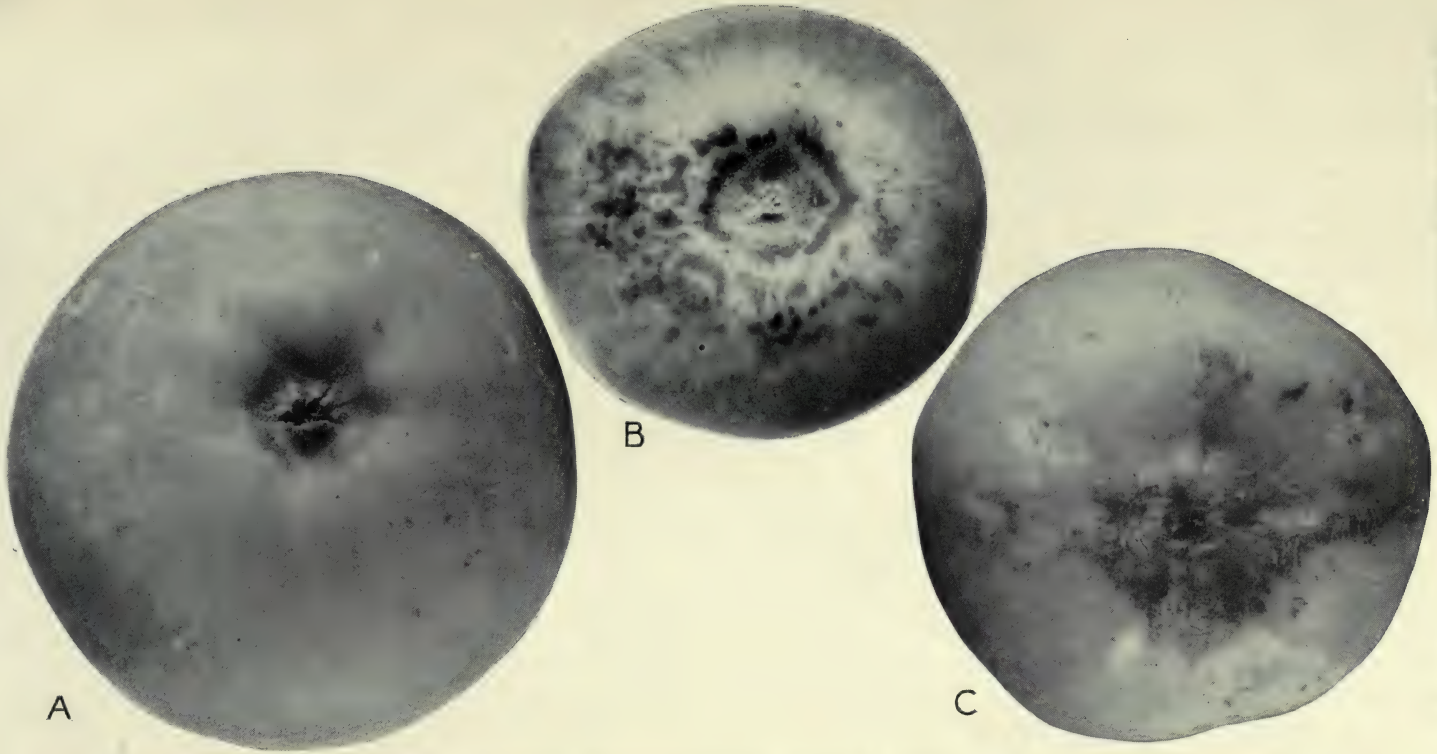


FIGURE 4.—Effect of spraying with an emulsion of a heavy oil added to the lead arsenate on the size of apples produced, Yakima, Wash., 1926

In 1927, therefore (see Table 17), experiments were made with the lighter mineral seal oil, in comparison with the technical oil, both alone and in combination with lead arsenate. The heavy dosage of the technical oil (Table 17, 1927, test 4) was apparently given in a wormier portion of the orchard than the other plats, but aside from this these tests show that the light oil is not so effective as the heavy oil. They also indicate that the addition of oil to the cover sprays of

[12] No. 4 (see p. 27).



EXAMPLES OF INJURY TO APPLES FROM THE USE OF A HEAVY OIL IN SPRAYING

A, Rome Beauty showing "Calyx ring"; B, Jonathan apple burned by spray; C, yellow Newtown showing russeting caused by spray.

lead arsenate results in better control and that the use of oil alone results in poorer control than the use of lead arsenate alone, although the fact that the crop was light in 1927 reduces somewhat the conclusiveness of these experiments.

TABLE 17.—*Orchard experiments with lubricating-oil emulsions, alone and in combination with lead arsenate, for the codling moth, Yakima, Wash., 1926 and 1927*

Test No.	Material used and number of applications	Total apples	Wormy apples [1]		Stung apples [1]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes
		Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
1926										
1	Lead arsenate 1–50, calyx and 5 cover sprays	15,022	714	4.8	1,253	8.3	88.0	2,505	1,621	0.65
2	The same as in test 1, plus 1 per cent technical oil [2] (emulsified), in first 4 cover sprays	6,384	105	1.6	210	3.3	95.4	375	255	.68
3	The same as in test 1, plus 2 per cent technical oil (emulsified), in first 4 cover sprays	9,333	94	1.0	203	2.2	96.9	345	237	.69
4	The same as in test 1, plus 4 per cent technical oil (emulsified), in first 4 cover sprays	4,521	20	.4	63	1.4	98.2	92	71	.77
1927										
1	Lubricating-oil (mineral seal) [3] emulsion, 0.75 per cent of oil [4]	2,941	162	5.5	339	11.5	84.4	648	429	0.66
2	Lubricating-oil (mineral seal) [3] emulsion, 1.5 per cent of oil [4]	5,835	181	3.1	345	5.9	91.8	672	429	.64
3	Lubricating-oil (technical) [2] emulsion, 0.75 per cent of oil [4]	2,636	34	1.3	102	3.9	95.0	166	127	.77
4	Lubricating-oil (technical) [2] emulsion, 1.5 per cent of oil [4]	4,303	169	3.9	358	8.3	88.8	715	497	.70
1	Lubricating-oil emulsion [5] used alone in 3 cover sprays	4,672	136	2.9	287	6.1	91.6	556	365	.66
2	Lubricating-oil emulsion [5] plus lead arsenate 1–50 used in 3 cover sprays	3,768	40	1.1	222	5.9	93.5	316	266	.84
3	Lead arsenate, 1 pound to 50 gallons	2,627	66	2.5	216	8.2	90.0	368	283	.77

[1] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.
[2] No. 5 (see p. 27).
[3] No. 4 (see p. 27).
[4] Oil emulsions used for calyx, first, second, and third cover sprays; lead arsenate, 1 pound to 50 gallons added to calyx spray and used alone in fourth cover spray.
[5] The figures include both mineral seal and technical oils at ¾ per cent and 1½ per cent dilutions. Lead-arsenate and oil emulsion used in calyx spray; lead arsenate alone in fourth cover spray.

There was a definite difference in the degree of injury produced by the two oils, the size of the fruit not being reduced by the light oil, and the percentage of fruit showing a dark calyx ring being less. These effects of the use of oil are shown in Table 18.

Again in 1928 experiments showed that oil used in several cover sprays alone resulted in more wormy fruit than a schedule of lead arsenate alone. (Table 19.)

In 1929 orchard experiments with oil were confined to the addition of the oil to some other material. Adding oil to all of the cover sprays of lead arsenate improved the control somewhat, except in the case of the three-fourths of 1 per cent light oil. (Table 19.) A medium oil (tests 2 and 4, 1929) was used that was considerably better than the light mineral seal oil, and this did not cause any

reduction in size or the discoloration of the calyx end such as resulted from the use of a heavy oil. The addition of oil to only two cover sprays (test 5, 1929) also resulted in somewhat cleaner fruit than was obtained with lead arsenate alone. The use of oil with other materials than lead arsenate is discussed elsewhere in this bulletin.

TABLE 18.—*Effect of the use of oil in sprays on the size of and injury to apples, Yakima, Wash., 1927*

Material used	Apples per box	Apples showing calyx ring	Material used	Apples per box	Apples showing calyx ring
	Number	*Per cent*		*Number*	*Per cent*
Lead arsenate alone	68.8	0	Technical oil,[2] ¾ per cent	69.2	44.4
Mineral seal oil,[1] ¾ per cent	64.5	12.7	Technical oil,[2] 1½ per cent	80.4	53.0
Mineral seal oil,[1] 1½ per cent	61.4	22.3			

[1] No. 4 (see p. 27). [2] No. 5 (see p. 27).

TABLE 19.—*Orchard experiments with lubricating-oil emulsions for the codling moth, Yakima, Wash., 1928 and 1929*

1928

Test No.	Material used[1]	Total apples	Wormy apples[2]		Stung apples[2]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes
		Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
1	Lead arsenate 1–50 alone	4,878	401	8.2	539	11.0	83.1	1,240	716	0.58
2	Lead arsenate 1–50, calyx and fourth cover spray; lubricating-oil (mineral seal)[3] emulsion 1½, first three cover sprays	7,856	792	10.1	771	9.8	80.6	2,016	968	.48
3	The same as test No. 2 except that technical oil[4] was used	4,090	391	9.6	433	10.6	81.8	1,108	597	.54

1929

1	Lead arsenate 1–50, plus mineral seal oil[5] (emulsified) (0.75 per cent of oil) added to all cover sprays	6,332	1,025	16.2	894	14.1	73.1	2,576	1,155	0.45
2	Lead arsenate 1–50, plus summer oil[5] (emulsified) (0.75 per cent of oil) added to all cover sprays	7,830	816	10.4	874	11.2	80.7	2,312	1,139	.49
3	Lead arsenate 1–50, plus mineral seal oil[5] (emulsified) (1.5 per cent of oil) added to all cover sprays	13,300	647	4.9	1,160	8.7	87.4	2,393	1,525	.64
4	Lead arsenate 1–50, plus summer oil[5] (emulsified) (1.5 per cent of oil) added to all cover sprays	9,746	344	3.5	561	5.8	91.4	1,140	701	.61
5	Lead arsenate 1–50, plus summer oil[5] (emulsified) (0.75 per cent of oil) added to second and fifth cover sprays only	11,720	1,552	13.2	1,990	17.0	73.2	4,778	2,663	.56
6	Lead arsenate 1–50	12,211	1,897	15.5	2,126	17.4	70.8	5,504	2,869	.52
7	Check (unsprayed)	3,408	2,450	71.9	485	14.2	24.0	5,686	587	.10

[1] Proportions are pounds to gallons.
[2] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.
[3] No. 4 (see p. 27). [4] No. 5 (see p. 27). [5] No. 6 (see p. 27).

It is concluded from all of these tests that for effective control of the codling moth without significant injury to the fruit or trees a medium oil, having a Saybolt viscosity of from 65 to 75 seconds, and a high sulphonation test, should be used in the proportion of slightly less than 1 per cent. It should be added to not more than three or four of the lead-arsenate cover sprays, in those applications occurring when the highest percentage of eggs is on the trees.[13] This is in accord with the findings of the western cooperative oil-spray project (*9*).

NICOTINE

In 1915 and 1916 De Sellem (*1*), working at Yakima, experimented with nicotine sulphate for codling-moth control and obtained some very good results, although the orchards used were not particularly wormy in 1916. Lovett (*3, p. 50*) reported a very high mortality of codling-moth eggs when sprayed with nicotine, the number of eggs used in his tests, however, being very limited.

LABORATORY EXPERIMENTS

A test was made with codling-moth eggs by the writers in 1923, using 40 per cent nicotine sulphate at 1 to 800, with casein spreader, 1 pound to 200 gallons. Thirty per cent of the sprayed eggs failed to hatch as compared with 26 per cent of the unsprayed eggs. This was so unpromising that no further tests were made until 1927. At that time more thorough tests (Table 20) indicated that in warm weather 40 per cent nicotine sulphate, at a dilution of 1 to 800, would kill over 50 per cent of the eggs, whether or not soap was added; and that although the mortality dropped in cool weather, this drop was offset by the addition of sodium bisulphate. The effect of temperature was examined further, and a graph of all of the tests of nicotine sulphate and soap (fig. 5) shows a definite increase in mortality with an increase in temperature. There was no indication of a difference in mortality dependent on the age of the eggs.

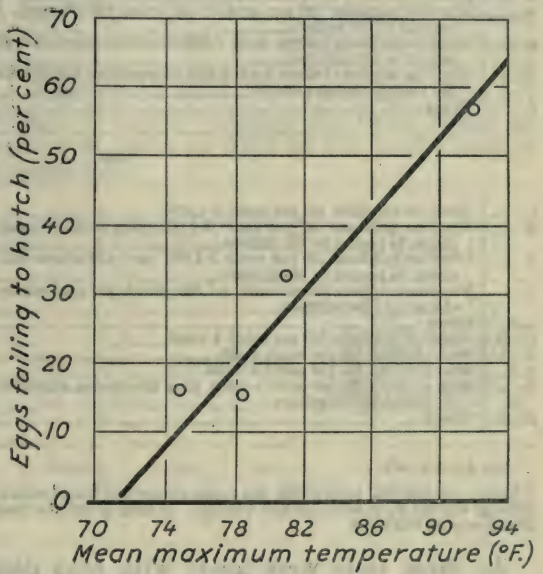


FIGURE 5.—Effect of temperature on the value of nicotine sulphate and soap when used to destroy codling-moth eggs, Yakima, Wash., 1927

[13] Experiments by H.C. Diehl, Bureau of Plant Industry, not yet published, have shown that oil used in this manner does not materially interfere with spray-residue removal.

TABLE 20.—*Laboratory experiments with nicotine sulphate on the eggs and larvae of the codling moth, Yakima, Wash., 1927 and 1928*

Test No.	Material used	Total eggs	Eggs dead		Total eggs producing larvae that entered fruit
		Number	*Number*	*Per cent*	*Per cent*
	1927				
1	Nicotine sulphate (40 per cent) 1–1,600	188	70	37.2	37.2
2	Nicotine sulphate (40 per cent) 1–800	59	30	50.8	27.1
3	Nicotine sulphate (40 per cent) 1–800, plus fish-oil soap, 3 pounds to 100 gallons	102	57	55.9	24.5
4	Check	118	21	17.8	72.0
5	Nicotine sulphate (40 per cent) 1–800, plus fish-oil soap, 3 pounds to 100 gallons	342	54	15.8	18.7
6	Nicotine sulphate (40 per cent) 1–800, plus casein spreader, ½ pound to 100 gallons	168	38	22.6	13.7
7	Nicotine sulphate (40 per cent) 1–800, plus sodium bisulphate, 1½ pounds to 100 gallons	294	165	56.1	2.4
8	Check	191	8	4.2	55.0
	1928				
1	Nicotine sulphate (40 per cent) 1–1,600	381	228	59.8	16.3
2	Nicotine sulphate (40 per cent) 1–1,600, plus sodium bisulphate, ½ pound to 100 gallons	382	149	39.0	14.9
3	Nicotine sulphate (40 per cent) 1–1,600, plus aluminum sulphate, ½ pound to 100 gallons	365	220	60.3	10.4
4	Nicotine sulphate (40 per cent) 1–1,600, plus ¾ per cent mineral seal oil [1] (emulsified)	521	449	86.2	4.8
5	Check	335	39	11.6	72.8
6	Nicotine sulphate (40 per cent) 1–1,600	124	88	71.0	8.1
7	Free nicotine (50 per cent) 1–800	251	136	54.2	12.4
8	Free nicotine (50 per cent) 1–1,600	162	57	35.2	32.1
9	Free nicotine (50 per cent) 1–1,600, plus aluminum sulphate, ½ pound to 100 gallons	272	106	39.0	27.9
10	Check	413	60	14.5	57.4

[1] No. 4 (see p. 27).

NOTE.—In the 1927 tests 1 to 4, the mean maximum temperature between spraying and the hatching of the eggs was 92° F.; in tests 5 to 8, it was 75°. In tests of 1928 the mean maximum temperature for one week after spraying was 85° F.

As these tests were made with eggs deposited on apples, it was possible to carry them further and determine the percentage of the total number of eggs that produced larvae able to enter the fruit. These percentages are given in the final column of Table 20. In no case did the total of the dead eggs and of the larvae entering the fruit equal the total number of eggs used, some larvae being lost. The number lost was invariably greater on the sprayed apples than on those unsprayed, indicating that the nicotine is toxic to some of the larvae after they hatch, and before they begin to feed. Observations have shown this to be the case, many larvae placed on apples recently sprayed with nicotine becoming apparently paralyzed and dropping from the fruit without feeding. More eggs hatched on both sprayed and unsprayed apples in cool weather than in warm weather, but fewer of the larvae were able to enter the apples, probably owing to the slower volatilization of the nicotine in cool weather. The results with nicotine sulphate and sodium bisulphate were particularly good.

TESTS WITH NICOTINE IN COMBINATIONS

In 1928, during warm weather, nicotine sulphate was tested at a concentration of 1–1,600, alone and with sodium bisulphate, alumi-

num sulphate, and an oil emulsion. (Table 20.) The best results were obtained with the combination of nicotine sulphate and oil, since the oil has a lethal effect on the eggs which the other two materials do not have. The sodium bisulphate, used one-third as strong as in 1927, seemed to have little direct value, but both it and the aluminum sulphate apparently prolonged the action of the nicotine and thus prevented many larvae from entering the fruit. Free nicotine was also tried, and its toxicity was found to be less than that of nicotine sulphate. (Table 20, 1928, tests 7 to 9.)

A direct comparison was made of nicotine sulphate and lead arsenate (Table 21), sprayed on apples on which eggs had been deposited one or two days previously. A smaller percentage of the eggs sprayed with nicotine hatched than of those sprayed with lead arsenate, the latter having no effect on hatching. Of the larvae that did emerge, approximately the same percentage entered the fruit in the two tests, indicating that the two treatments were equally effective in preventing entrance, even though this occurred 10 days after spraying. The net result was that the percentage of larvae entering the fruit, based on the original number of eggs, was twice as high in the lead arsenate test as in the nicotine sulphate test.

TABLE 21.—*Laboratory experiments comparing the effect of nicotine sulphate and lead arsenate on the eggs and larvae of the codling moth, Yakima, Wash., 1928*

Test No.	Material used	Total eggs	Eggs hatched		Eggs producing larvae that entered fruit based on number that hatched	Eggs producing larvae that entered fruit based on total number of eggs in test
		Number	*Number*	*Per cent*	*Per cent*	*Per cent*
1	Nicotine sulphate 1–1,600	182	78	42.9	25.6	11.0
2	Lead arsenate 1–50	197	173	87.8	25.4	22.3
3	Check	63	50	79.4	82.0	65.0

In 1927, during very warm weather, a test was made also of the toxic effect of nicotine sulphate on codling-moth eggs deposited from two to six days after spraying. Even under these conditions more eggs failed to hatch and fewer larvae entered the fruit than in the check (Table 22), but the difference is not so great as in the case of apples sprayed after the deposition of eggs. (Compare test No. 1, Table 22, with No. 3, 1927, Table 20.) In this test the addition of sodium bisulphate did not increase the mortality of eggs but did reduce the percentage of larvae entering the fruit, indicating that the nicotine is retained better by the sodium bisulphate than by the soap.

These results suggested that sodium bisulphate or aluminum sulphate might be of value in retarding the volatilization of the nicotine. Since for codling-moth control it is necessary to retain the toxicity for two or three weeks, an experiment was made in which nicotine sulphate with soap and with sodium bisulphate were directly compared under similar conditions of temperature, treatment, etc. Apples were sprayed with the two combinations, and at intervals codling moth larvae were placed on them, 10 apples being used each time for each combination, and 10 larvae being placed on each apple. The percentage of larvae surviving the nicotine-soap combination rose much

TABLE 22.—*Laboratory experiments with nicotine sulphate on eggs of the codling moth deposited after spraying, Yakima, Wash., 1927*

Test No.	Material used	Interval between spraying and deposition of eggs	Total eggs	Eggs dead		Eggs producing larvae that entered fruit based on total number of eggs in test
		Days	*Number*	*Number*	*Per cent*	*Per cent*
1	Nicotine sulphate 1-800, plus fish-oil soap, 3 pounds to 100 gallons	2-6	577	155	26.9	39.2
2	Nicotine sulphate 1-800, plus sodium bisulphate, 1½ pounds to 100 gallons	6	216	59	27.3	15.3
3	Check		619	111	17.9	72.0

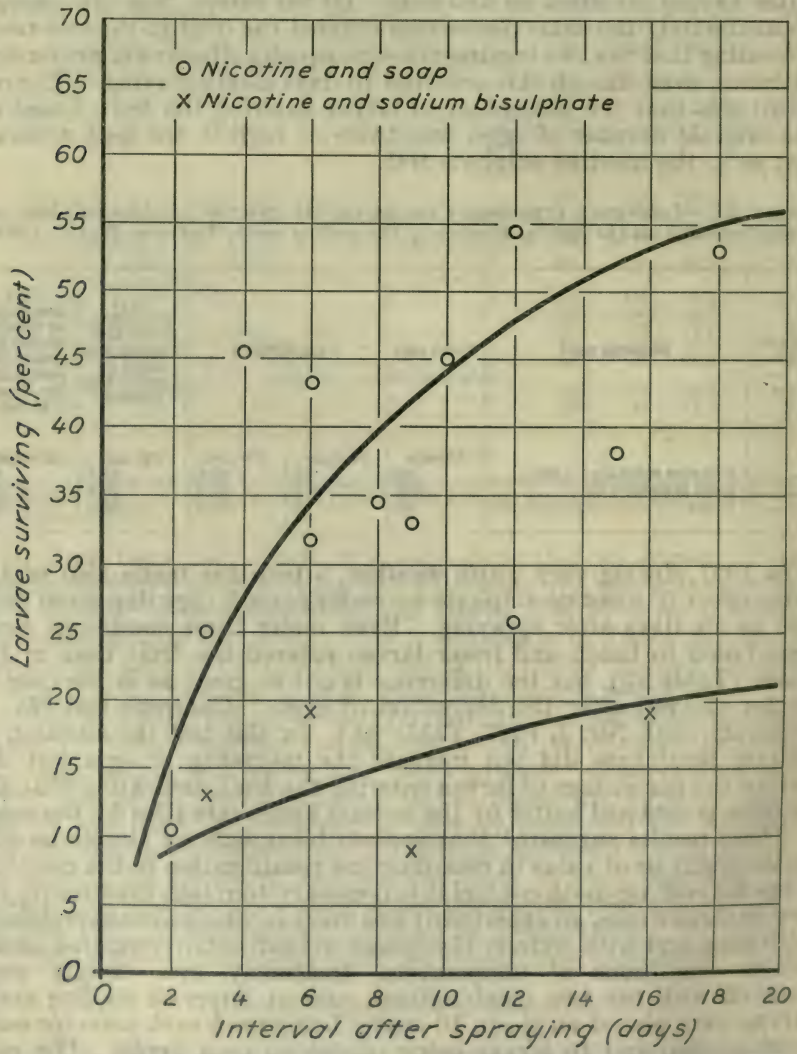


FIGURE 6.—Percentages of codling-moth larvae surviving after being placed at intervals on apples sprayed with nicotine sulphate in combination with soap and with sodium bisulphate, Yakima, Wash., 1927

more rapidly than that of the larvae surviving the mixture of nicotine sulphate and sodium bisulphate. (Fig. 6.) For comparison the percentages of larvae surviving after being placed on apples sprayed with lead arsenate and on unsprayed apples were 42 and 66, respectively, regardless of the time.

ORCHARD EXPERIMENTS

Orchard tests are necessary to show the true value of a spray containing nicotine, because the varying weather conditions and the growth of the fruit can not be reproduced in the laboratory. In 1921 and 1922 the addition of nicotine sulphate and fish-oil or linseed-oil soap to all of the cover sprays of a regular lead-arsenate schedule had been tried, and although the control was improved by this addition, the improvement was not sufficient to warrant the added expense. The experiment was tried again in 1927, except that no lead arsenate was used after the first cover spray. Results in a lightly infested orchard were fair, but not so good as from the use of lead arsenate alone. In a heavily infested orchard a similar experiment was tried, lead arsenate being used for the first two sprays and nicotine sulphate (1–800) with nothing added for the remaining cover sprays. Twice as much fruit became wormy in this plat as in an adjoining plat sprayed throughout the season with lead arsenate. It was evident that these combinations were not successful.

TABLE 23.—*Orchard experiments with nicotine sulphate, alone and in combination with glycerine and oil, for the codling moth, Yakima, Wash., 1928 and 1929*

Test No.	Material used [1]	Dilution of nicotine	Total apples	Wormy apples [2]		Stung apples [2]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes
			Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
1928											
1	Nicotine sulphate	1–800	13,594	1,146	8.4	363	2.7	89.6	1,801	410	0.23
2	do	1–1,600	15,241	1,708	11.2	649	4.3	86.1	3,015	767	.25
3	The same as in test 2, plus aluminum sulphate, 1 pound to 200 gallons.	1–1,600	11,032	822	7.5	373	3.4	90.0	1,530	432	.28
4	The same as in test 2, plus ¾ per cent mineral seal oil [3] (emulsified).	1–1,600	10,160	559	5.5	329	3.2	91.9	1,030	376	.37
1929											
1	Nicotine sulphate (40 per cent), plus ½ per cent glycerin.	1–800	9,556	5,041	52.8	1,888	19.8	40.2	12,775	2,557	0.20
2	Nicotine sulphate (40 per cent), plus ¾ per cent summer oil [4] (emulsified).	1–800	10,484	2,245	21.4	1,280	12.2	70.7	5,211	1,584	.30
3	Nicotine sulphate (40 per cent), plus ¾ per cent summer oil [4] (emulsified).	1–1,600	11,582	3,742	32.3	1,518	13.1	60.9	8,597	1,964	.23
4	Lead arsenate 1 pound to 50 gallons; nicotine sulphate and ¾ per cent summer oil [4] added to second and fifth cover sprays.	1–1,600	11,856	1,971	16.6	2,397	20.2	68.1	6,485	3,472	.54
5	Lead arsenate, 1 pound to 50 gallons.	.....	12,749	3,247	25.5	4,598	36.1	50.7	14,261	8,024	.56

[1] Lead arsenate, 1 pound to 50 gallons, used alone for calyx and first cover sprays in all tests. In all subsequent applications only the materials shown were used.

[2] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.

[3] No. 4 (see p. 27).

[4] No. 6 (see p. 27).

In 1928, therefore, orchard experiments were made with aluminum sulphate and with oil emulsion added to the nicotine sulphate in comparison with the nicotine used alone. These materials were used in all applications following a calyx spray and a first cover spray of lead arsenate. Direct comparison could not be made with plats that were

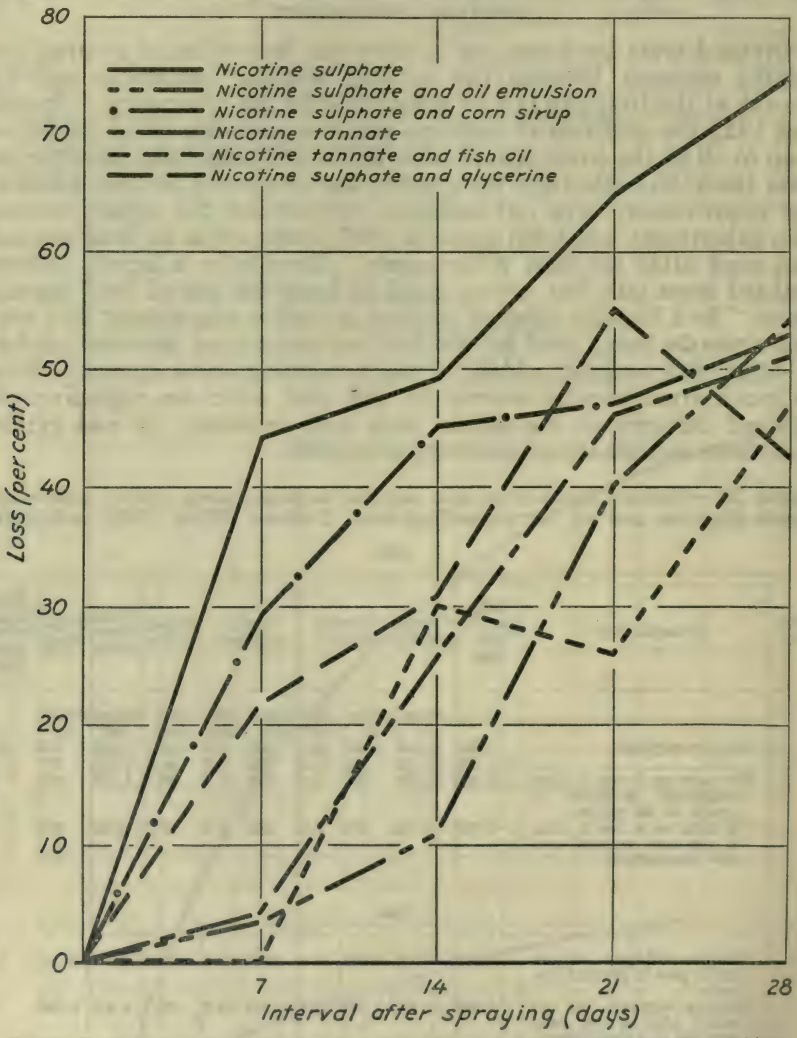


FIGURE 7.—Percentage of nicotine lost from apple foliage at intervals after spraying, Yakima, Wash., 1929

being sprayed with lead arsenate because of a difference in infestation, but much better control resulted from the addition of either of these materials to the nicotine (Table 23) than from the nicotine alone. The oil was the better of the two, probably on account of its effect on the eggs.

Variations in the use of nicotine sulphate were experimented with in 1929. It was tried with corn sirup and glycerin. Nicotine oleate and nicotine tannate were also tested. Chemical determinations [14]

[14] Made by Bureau of Chemistry and Soils laboratory, Yakima, Wash.

(fig. 7) indicated that neither corn sirup nor glycerin retained the nicotine as effectively as oil.

Nicotine tannate showed promise, both alone and with fish oil, and further experiments will be made with these sprays. Nicotine oleate burned the fruit (pl. 2, E) and foliage severely.

In the orchard experiments were conducted with nicotine sulphate combined with glycerin and with oil emulsion. (Table 23.) The results from the nicotine-glycerin combination were very poor. The nicotine-oil combinations, however, gave very good results in terms of percentage of clean apples, and where this combination was used in four cover sprays (Nos. 2 and 3, 1929) the percentage of stung apples was materially reduced.

From all these experiments it may be concluded that nicotine sulphate alone, although it has some control value against the egg, and some immediate larvicidal value, can not be depended on for control of the codling moth; but that the combination of nicotine sulphate and oil is a very effective one for control because it destroys many of the eggs, and sufficient nicotine is retained to kill larvae for some time. This combination may be substituted for lead arsenate in one or more cover sprays, or it may be added to the lead arsenate.

PYRIDINE DERIVATIVES

Richardson and Smith (*6*) found that certain compounds related to nicotine, known as dipyridyls, were very toxic to aphids. A crude mixture of the sulphates of these compounds and a crude sample of benzyl pyridine furnished by the Bureau of Chemistry and Soils were tried on codling-moth larvae by the writers. (Table 24.) Neither of them were equal in toxicity to lead arsenate or nicotine sulphate, except the crude benzyl pyridine at 1 to 100. (Test 4.) At this strength, however, this material caused brown spots to appear on the sprayed fruit.

TABLE 24.—*Laboratory experiments with pyridine derivatives on the larvae of the codling moth, Yakima, Wash., 1928*

Test No.	Material used	Dilution	Worms entering fruit		Worms causing stings		Total blemishes	Ratio of stings to total blemishes
			Number	*Per cent*	*Number*	*Per cent*	*Per cent*	
1	Dipyridyl sulphate	1–100	27	54	2	4	58	0.07
2	do	1–200	25	50	7	14	64	.22
3	do	1–400	33	66	4	8	74	.11
4	Crude benzyl pyridine	1–100	15	30	4	8	38	.21
5	do	1–200	22	44	5	10	54	.19
6	do	1–400	22	44	9	18	62	.29
7	Lead arsenate	1–50	16	32	10	20	52	.38
8	Check	-------	26	52	3	6	58	.10
9	Crude benzyl pyridine	1–100	18	18	13	13	31	.42
10	do	1–200	19	19	10	10	29	.34
11	do	1–400	21	21	14	14	35	.40
12	Nicotine sulphate (40 per cent)	1–800	4	4	5	5	9	.56
13	Lead arsenate	1–50	15	15	19	19	34	.56
14	Check	-------	35	35	14	14	49	.29
15	Crude benzyl pyridine (1–100) emulsified with calcium caseinate 1 gram to 15 cubic centimeters	-------	24	24	14	14	38	.37
16	Crude benzyl pyridine (1–200) emulsified with calcium caseinate 1 gram to 15 cubic centimeters	-------	23	23	15	15	38	.40
17	Crude benzyl pyridine (1–400) emulsified with calcium caseinate 1 gram to 15 cubic centimeters	-------	35	35	8	8	43	.19
18	Nicotine sulphate (40 per cent)	1–800	7	7	4	4	11	.36
19	Lead arsenate	1–50	15	15	18	18	33	.55
20	Check	-------	45	45	10	10	55	.18

DERRIS AND PYRETHRUM

A commercial extract of Derris, labeled as containing 5 per cent active ingredients, was tested against the eggs at a concentration of 1 to 800. Of 251 eggs sprayed, 27.8 per cent failed to hatch, as compared with 23 per cent of 374 unsprayed eggs. The same extract, at concentrations of 1 to 400 and 1 to 800, was tested as a larvicide. Other materials tested in this manner included an alcoholic extract of Derris root,[15] a kerosene extract of pyrethrum, and a commercial pyrethrum extract, labeled as containing 92 per cent active ingredients. With the exception of the latter material, none of these extracts had any appreciable larvicidal value when tested within 48 hours after spraying.

Experiments were then made with the commercial Derris extract, and with three commercial pyrethrum extracts, used with and without a lubricating-oil emulsion, and sprayed on fruits to find out whether the oil would cause these materials to remain toxic longer. (Table 25.) All of the pyrethrum extracts were very toxic within 24 hours of spraying, but apparently had lost most of their toxicity a week later. The Derris was quite ineffective, even when freshly applied. The addition of oil emulsion had no beneficial effect.

TABLE 25.—*Laboratory experiments with Derris and pyrethrum on the larvae of the codling moth, Yakima, Wash., 1929*

Test No.	Material used	Percentage of worms entering fruit—	
		1 day after spraying	7 days after spraying
1	Commercial Derris extract 1–400	34	48
2	Commercial Derris extract 1–400, plus ¾ per cent lubricating oil (emulsified)	32	50
3	Commercial Derris extract 1–800, plus ¾ per cent lubricating oil (emulsified)	44	48
4	Pyrethrum extract No. 1, 1–200	8	48
5	Pyrethrum extract No. 1, 1–200, plus ¾ per cent lubricating oil (emulsified)	8	50
6	Pyrethrum extract No. 1, 1–400, plus ¾ per cent lubricating oil (emulsified)	8	44
7	Pyrethrum extract No. 2, 1–100	10	36
8	Pyrethrum extract No. 2, 1–100, plus ¾ per cent lubricating oil (emulsified)	0	36
9	Pyrethrum extract No. 3, 1–400	0	40
10	Pyrethrum extract No. 3, 1–800	10	40
11	Pyrethrum extract No. 3, 1–800, plus ¾ per cent lubricating oil (emulsified)	10	54
12	Lead arsenate 1–50	18	28
13	Check	34	64

The alcoholic extract of Derris and the kerosene extract of pyrethrum, in orchard experiments, were practically worthless, the fruit becoming extremely wormy. In an orchard experiment with the commercial pyrethrum extract No. 1, and lubricating-oil emulsion, 37.3 per cent of the fruit became wormy, as compared with 25.5 per cent in a plat sprayed with lead arsenate. Judging from the laboratory results, much of this control may be attributed to the effect of the oil on the eggs. An orchard experiment with the commercial Derris extract was discontinued because injury to the fruit (pl. 2, F) and foliage developed and much of the fruit was becoming wormy.

[15] This sample of Derris root was later found to be low in total extract and to contain not more than traces of rotenone, which explains the very poor results obtained with it.

COMPOSITION OF SPRAY MATERIALS

The characteristics of the oils used and the formula for the nicotine tannate are given below:

No. 1. Red engine oil:		
Volatility (4 hours at 110° C.)	per cent	0. 4
Viscosity (Saybolt at 100° F.)	seconds	230
Specific gravity at 20° C.		0. 921
Unsulphonated residue (38 N acid)	per cent	50
No. 2. Brown neutral oil:		
Volatility	per cent	2. 7
Viscosity	seconds	116
Specific gravity		0. 922
Unsulphonated residue	per cent	49
No. 3. Crystal oil:		
Volatility	per cent	0. 84
Viscosity	seconds	122
Specific gravity		0. 871
Unsulphonated residue	per cent	95. 2
No. 4. Mineral seal oil:		
Viscosity	seconds	52
Unsulphonated residue	per cent	82
No. 5. Technical oil:		
Viscosity	seconds	129
Unsulphonated residue	per cent	89
No. 6. Summer oil:		
Viscosity	seconds	78
Unsulphonated residue	per cent	77
No. 7. Nicotine tannate:		
Tannic acid	pounds	3
Nicotine (50 per cent)	pound	1
Water	gallons	100

In No. 7 the tannic acid is sifted into 25 gallons of water while it is being agitated, the nicotine is added, and then the remainder of the water.

SUMMARY

The demand for more effective methods of controlling the codling moth that would not leave objectionable spray residues has been the chief reason for the studies described in this bulletin.

The use of lead arsenate at 2 pounds to 50 gallons, or of an increased number of applications at 1 pound to 50 gallons, improved the control, but also resulted in more arsenical residue.

Casein spreader, in small quantities, caused the lead arsenate to be somewhat more effective, but in larger quantities it did not have this result. Fish oil also increased the effectiveness of the lead arsenate, but made residue removal more difficult. Soap, glue, and flour paste reduced the value of the arsenical.

Thirteen nonlead arsenicals were tested, but none of them controlled the codling moth as well as lead arsenate, and several of them damaged the fruit or foliage severely. Barium arsenate, zinc arsenate, and manganese arsenate were the most effective.

Lubricating-oil sprays proved to be valuable against the eggs, and they also had some toxic effect on eggs deposited a few days after spraying, but did not repel ovipositing moths. There was little effect on the larvae. Heavy or relatively unrefined oils were often injurious to the fruit or foliage. Oil sprays alone were not so efficient as lead arsenate.

It was concluded that in order to use oil safely and effectively for codling-moth control a medium oil with a Saybolt viscosity of

65 to 75 seconds and a large proportion of unsulphonatable residue should be added in a proportion of slightly less than 1 per cent to not more than three or four lead arsenate cover sprays.

Nicotine sulphate was somewhat toxic to codling-moth eggs and larvae in warm weather, but by itself was of less value than lead arsenate. Of the materials tested to prevent too rapid volatilization of the nicotine, lubricating oil gave the best results, and very good control was obtained with a combination of nicotine sulphate, diluted to 1–800 or 1–1,600, and a 1 per cent lubricating-oil spray. This combination is of value when substituted for lead arsenate in one or more cover sprays.

Poor results were obtained with crude dipyridyl sulphate and crude benzyl pyridine. Derris, in the forms tested, was ineffective, and pyrethrum extracts were effective only for a short time after being applied.

LITERATURE CITED

(1) [De Sellem, F. E.]
[1917]. nicotine sulphate for codling moth control. Yakima Co., Wash., Hort. Dept. Ann. Rpt. 1916: 62–72.

(2) Hood, C. E.
1929. fish oil as an adhesive in lead-arsenate sprays. U. S. Dept. Agr. Tech. Bul. 111, 28 p., illus.

(3) Lovett, A. L.
1920. insecticide investigations. Oreg. Agr. Expt. Sta. Bul. 169, 55 p., illus.

(4) Melander, A. L.
1920. an index number for rating codling moth treatments. Jour. Econ. Ent. 13: 456–458.

(5) Newcomer, E. J.
1926. laboratory experiments with arsenicals in the control of the codling moth. Jour. Agr. Research 33: 317–330.

(6) Richardson, C. H., and Smith, C. R.
1926. toxicity of dipyridyls and certain other organic compounds as contact insecticides. Jour. Agr. Research 33: 597–609, illus.

(7) Smith, R. H.
1926. the efficacy of lead arsenate in controlling the codling moth. Hilgardia 1: [403]–453, illus.

(8) Spuler, A.
1929. spraying experiments for codling moth control. Wash. Agr. Expt. Sta. Bul. 232, 70 p., illus.

(9) Western Cooperative Oil Spray Project
1930. suggestions for use of oil sprays in 1930. Jour. Econ. Ent. 23: 289–290.

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EFFECT OF PLANT ARRANGEMENT, EQUIPMENT, AND METHODS OF OPERATION IN RELATION TO BREAKAGE OF BOTTLES IN MILK PLANTS

By C. E. CLEMENT, *Associate Market-Milk Specialist;* J. B. BAIN, *Associate Market-Milk Specialist;* and FRED M. GRANT, *Assistant Market-Milk Specialist, Division of Market-Milk Investigations, Bureau of Dairy Industry*

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INTRODUCTION

The breakage of bottles in milk plants is an item of great importance, and milk-plant operators have given considerable attention to it in recent years. Without doubt a large part of the breakage of bottles is indirectly due to imperfections in the glass and to variations in the quality and in the annealing of the glass, but it was not within the field of this study to go into these factors, it being assumed that they would not vary greatly between plants. In order to determine whether the plant layout and the equipment had any effect on the amount of breakage, studies were made by the Bureau of Dairy

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Industry in milk plants having various arrangements and using different types of equipment. The broken glass was collected as far as possible after each operation in the plant for a period of a few days. The glass collected at each point was weighed, and a careful study was made of the equipment and its arrangement in each plant. The broken glass was taken out at the following points: Checking-in platform, feed end of washer, discharge end of washer, the fillers, and the milk-storage room. The breakage of glass found at these points is expressed in pounds of glass per 1,000 bottles handled, unless otherwise indicated.

The observations made of the layout, equipment, and operation of each plant at the time the records were obtained have been supplemented by careful studies of the drawings of the plants. This bulletin presents information on the plants studied, compares plant layouts, and discusses the effects that the different arrangements of plants, types and arrangement of equipment, and methods of handling bottles had on breakage of bottles.

LOSSES FROM CHIPPED BOTTLES

The number of bottles that have to be thrown out because of chipped or cracked tops or lips is an important item. At 52 plants where the chipped bottles were kept separate from the other breakage, the average breakage due to chipped bottles was 25 per cent of the total breakage. The average total breakage, including chipped bottles, for these 52 plants was 15.5 pounds per 1,000 bottles filled. Of this 15.5 pounds, 3.9 pounds were bottles which could not be used again because of being badly chipped. The average of 3.9 pounds of bottles chipped per 1,000 bottles handled shows the importance of this item of loss in the average milk business.

There was a decided variation in the amount of chipped bottles at the 52 plants where the studies were made. (Table 1.) For example, 6 plants had a breakage from chipped bottles of less than 1 pound per 1,000 bottles handled, whereas chipped bottles at 7 plants amounted to over 7 pounds per 1,000 bottles handled.

TABLE 1.—*Pounds of glass in chipped bottles in 52 milk plants*

Item	Pounds of glass in chipped bottles, per 1,000 bottles handled											
	1 pound or less	1.1 to 2 pounds	2.1 to 3 pounds	3.1 to 4 pounds	4.1 to 5 pounds	5.1 to 6 pounds	6.1 to 7 pounds	7.1 to 8 pounds	8.1 to 9 pounds	9.1 to 10 pounds	10.1 to 11 pounds	Total
Average pounds of broken bottles	0.6	1.8	2.5	3.5	4.6	5.3	6.9	7.6	8.7	-----	10.6	3.9
Number of plants in group	6	8	12	6	5	4	3	2	3	-----	2	52

At one plant a study was made to determine the number of chipped bottles of different sizes, and whether they were returned from retail or family trade or from wholesale or store trade. As a special "store bottle" was used for wholesale trade at this particular plant, it was possible to determine separately the number of store bottles and family bottles chipped. The results of the study made at this plant for a period of eight days are shown in Table 2.

TABLE 2.—*Number of chipped bottles thrown out at one milk plant in eight days*

Day	Quarts			Pints			Jars [1]			All sizes		
	Store	Retail	Total	Store	Retail	Total	Store	Retail	Total	Total store	Total retail	Total
1	466	124	590	71	12	83	82	44	126	619	180	799
2	465	140	605	44	27	71	17	89	106	526	256	782
3	371	53	424	55	14	69	26	178	204	452	245	697
4	422	118	540	97	25	122	52	78	130	571	221	792
5	366	79	445	72	22	94	25	70	95	463	171	634
6	300	31	331	111	1	112	26	78	104	437	110	547
7	195	23	218	72	33	105	29	51	80	296	107	403
8	117	21	138	41	24	65	25	30	55	183	75	258
Total chipped bottles	2,702	589	3,291	563	158	721	282	618	900	3,547	1,365	4,912
Bottles filled	301,733	285,251	586,984	63,307	95,091	158,398	32,559	327,816	360,375	397,599	708,158	1,105,757
Bottles chipped per 1,000 filled	8.9	2.1	5.6	8.9	1.7	4.6	8.7	1.9	2.5	8.9	1.9	4.4

[1] Includes all bottles smaller than pint size.

Table 2 shows that the number of bottles chipped per 1,000 filled was quite uniform for bottles of all sizes. It also shows that for bottles of all sizes a much greater proportion of store or wholesale bottles was chipped than of the retail bottles used for family trade. Although it was not possible to take out all the chipped bottles at the checking-in platform when they were checked in from the routes, many of them being taken out at other points in the plants, observations at this plant and at other plants indicated that by far the greater proportion of the chipping was done after the bottles were loaded out and before their return to the plant for refilling. The high ratio of wholesale bottles to retail bottles chipped (approximately 4.7 to 1) also seems to support the assumption that most of the chipping of the bottles occurs on the routes rather than in the plant. Bottles of milk and cream sold through stores are handled many times and often receive considerable rough handling, especially when they are returned to the cases in the stores.

As most of the chipping seemed to occur while the bottles were out on the routes and the amount chipped in the plants themselves was apparently a minor factor, in studying the effect of the various plant arrangements and types of equipment on breakage the chipped bottles were kept separate from the other breakage as far as possible and have been eliminated in making the comparisons, except where it was evident that the chipping occurred in the plant.

RELATION OF SIZE OF PLANT TO BREAKAGE

The breakage weighed in 121 plants handling between 10,000 and 100,000 or more bottles daily indicated that size of plant had no direct influence on the number of bottles broken. (Table 3.) The average breakage for the 121 plants was 12.3 pounds per 1,000 bottles handled. It will be noted that the average for any group of plants varied only slightly from this general average. There were considerable variations in the plants within each group, however, indicating that factors other than size were responsible for the differences.

TABLE 3.—*Breakage of bottles in plants of different sizes*

Size of plant (number of bottles handled daily)	Plants	Average weight of glass broken per 1,000 bottles handled	Size of plant (number of bottles handled daily)	Plants	Average weight of glass broken per 1,000 bottles handled
	Number	*Pounds*		*Number*	*Pounds*
10,001 to 20,000	24	10.4	60,001 to 80,000	9	11.5
20,001 to 30,000	19	11.5	80,001 to 100,000	6	13.9
30,001 to 40,000	16	13.1	100,001 or over	18	13.7
40,001 to 60,000	17	13.1			
50,001 to 60,000	12	12.5	Total or average	121	12.3

DISTANCE TRAVELED BY BOTTLES IN PLANTS NOT A FACTOR IN BREAKAGE

A study of the plant layouts and of the breakage at the various small plants showed quite clearly that the distance the bottles traveled in the plants was not a factor in itself. The coefficient of correlation between the breakage and the distance the bottles traveled was only 0.18, indicating that there was little relation between the breakage and the distance in itself and that the methods used to transfer the bottles from place to place was the cause of the variations at the various plants. Day[1] states:

> Coefficients above 0.70 give almost certain evidence of correlation, and any above 0.50 are ordinarily significant; coefficients under 0.30 give very little indication of any definite connection between the variables.

BREAKAGE IN TRANSFERRING BOTTLES BETWEEN FLOORS

The amounts of breakage at 126 plants were compared, to determine the effect of transferring bottles from one floor to a higher or lower floor by conveyors, elevators, escalators, chutes, etc. (Table 4.) Direct delivery of bottles to a higher floor by the bottle washer itself was not considered a transfer. For example, it was considered as only one transfer where the bottles were sent from the street floor to the basement to be washed and the washer itself elevated them back to the street floor to be filled.

TABLE 4.—*Effect upon breakage of number of times bottles were transferred from one floor to another*

Number of transfers between floors	Plants	Bottles handled daily	Glass broken per 1,000 bottles handled		
			Before washing	At discharge end of washers plus breakage at fillers	Total
	Number	*Number*	*Pounds*	*Pounds*	*Pounds*
No transfers, all operations on one floor	79	37,345	4.6	5.6	11.4
One transfer	14	59,914	4.9	6.1	12.4
Two transfers	30	75,892	5.8	7.3	14.6
Three transfers	3	47,212	8.4	12.9	24.0

[1] Day, E. E. STATISTICAL ANALYSIS. p. 209. New York. 1925.

The breakage increased with the number of transfers. In the group of plants which carried on all the operations on one floor, the total plant breakage averaged only 11.4 pounds per 1,000 bottles filled, whereas it was 12.4, 14.6, and 24.0 pounds at the plants making 1, 2, and 3 transfers, respectively. At most of the 14 plants making only one transfer the bottles were washed in the basement (having been transferred to that point from the street floor by a conveyor or chute) and delivered to the street floor by the washer itself. The breakage at these plants was only slightly greater, on an average, than the breakage at the 79 plants carrying on all the operations on one floor.

At two of the plants making three transfers the bottles were washed in the basement and then elevated to the second floor; at one of these plants the bottles were filled and then transferred to the milk-storage room on the street floor, and at the other plant they were stored and allowed to cool on the second floor and later transferred to the street floor to be filled and stored. At the third plant the bottles were stacked in the basement, sent to the second floor for washing and filling, and then sent back to the milk-storage room on the first floor.

At those plants where the bottles were transferred twice, the average total plant breakage was 28 per cent greater than was found at those plants which carried on all their operations on one floor with no transfers, whereas the total plant breakage was 110 per cent larger in those plants which had three transfers. Of course, other factors may enter. For example, at two of the plants in the last group the bottles were washed by the old style "in-the-case" washer, which, as is shown on pages 16 to 18, tends to break more bottles than does the direct system of washing and filling, principally because of more handling and less accurate temperature control. Furthermore, these data do not necessarily prove that it is impossible to transfer bottles two or three times without an excessively high breakage resulting, provided the conveyors, etc., are of proper design and are kept in good repair. These data do indicate, however, that on an average the breakage is considerably greater at plants where the bottles are transferred two or three times than at plants where all the operations are performed on one floor, or at plants where the bottles are sent to the basement to be washed and the washer itself elevates them to the street floor with no further transfers.

EFFECT OF MOVING BOTTLES TO AN UPPER FLOOR TO BE WASHED, AS COMPARED WITH WASHING THEM ON THE GROUND FLOOR OR IN THE BASEMENT

Table 5 shows the effect of moving bottles to the second or upper floors upon breakage as compared with washing them on the street floor or sending them to the basement for washing where the washer delivered them to the street floor.

TABLE 5.—*Effect upon breakage of moving bottles to an upper floor to be washed as compared with washing them on the ground floor or in the basement*

Location of washer	Plants	Bottles filled daily	Glass broken per 1,000 bottles filled		
			Before washing	At discharge end of washers plus breakage at fillers	Total
	Number	*Number*	*Pounds*	*Pounds*	*Pounds*
On ground or street floor	64	41,126	3.7	5.6	10.2
In basement [1]	9	57,671	3.8	5.3	10.2
On floors above the street or ground floor	17	62,010	5.3	7.3	14.4

[1] Bottles are delivered to the ground floor by the washer itself.

At the plants with the washers on the ground or street floor, both the breakage before washing and the total plant breakage were lower than at the plants where the washers were on a floor above.

There was little difference in breakage between those plants where the washers were on the street or ground floor and those plants where the washers were in the basement and elevated the bottles to the street floor. Where the bottles were sent to an upper floor to be washed, the breakage before washing and the total plant breakage were considerably greater than at the plants in the other two groups. The total plant breakage in the group of plants with washers on the upper floors was 14.4 pounds, as compared with 10.2 pounds in each of the two groups of plants which had the washers either on the ground floor or in the basement—41 per cent greater than in the two latter groups.

COMPARISON OF TYPES OF CONVEYORS FOR MOVING BOTTLES TO BASEMENT

Power control of conveyors was found to be an effective means of moving cases carefully between floors and keeping the breakage of glass down. The relative amounts of breakage before washing in two groups of plants equipped with power-controlled and gravity conveyors, respectively, for moving the bottles to the basement to be stacked or washed are shown in Table 6.

TABLE 6.—*Comparison of the results with two types of conveyors for moving bottles to basement*

Type of conveyor	Plants	Glass broken before washing, per 1,000 bottles handled
	Number	*Pounds*
Power-controlled	9	3.6
Gravity	12	6.2

On an average more breakage before washing was found in plants which used gravity conveyors for moving the bottles to the basement

than in plants with power conveyors which controlled the movement of cases and prevented them from banging against each other.

EFFECT OF TRANSFERRING FILLED BOTTLES TO MILK-STORAGE ROOM ON FLOOR BELOW

While at some plants cases of filled bottles were moved between floors with small breakage, in general more bottles were broken between the filling and storage rooms where filled bottles were sent to lower floors. At plants where the filling room was on the second floor and the milk-storage room on the first floor, or the filling room was on the first floor and milk-storage room in the basement (as was found in one or two instances), there was twice as much breakage in the milk-storage room as at plants which had the filling and milk-storage rooms on the same floor. (Table 7.)

TABLE 7.—*Comparison of bottle breakage in moving filled cases from filling room to milk-storage room, when these rooms are on the same floor and when on of filled bottles to the milk-storage room on a lower floor*

Location of milk-storage room	Plants	Broken glass taken out in milk-storage room per 1,000 bottles handled
	Number	*Pounds*
On same floor	121	0.9
On a lower floor	21	2.0

EFFECT OF DIFFERENT TYPES OF CONVEYORS FOR MOVING FILLED CASES BETWEEN FLOORS TO MILK-STORAGE ROOM

The types of conveyors used to move the filled bottles between floors had an effect on the average quantity of glass taken out in the milk-storage room. (Table 8.) The average breakage in the milk-storage room of those plants using straight or spiral gravity conveyors was 2.4 pounds per 1,000 bottles handled, as compared with 1.4 pounds where power-controlled conveyors kept the cases from banging together and the bottles from striking each other.

TABLE 8.—*Effect upon breakage of different types of conveyors for moving cases of filled bottles to the milk-storage room on a lower floor*

Method of moving cases	Plants	Broken glass taken out in milk-storage room per 1,000 bottles handled
	Number	*Pounds*
Straight and spiral gravity conveyors	13	2.4
Power-controlled conveyors	8	1.4

Spiral roller conveyors required more attention than straight conveyors, especially when wet cases were rolled over them. Also, it was usually difficult to reach all sections of the spiral conveyors to

lubricate the bearings, with the result that bearings became worn and the conveyor was not kept in free-running, first-class condition. In order to overcome the retarding action as the rollers become worn, and the braking effect of the curves, such conveyors were frequently installed with pitches so steep that the cases raced down. Apparently, it is a very difficult matter to install spiral conveyors with the correct balance between diameter of the spiral and its pitch so cases will travel down freely and easily without either stopping or racing.

In one plant the breakage in the milk-storage room was 3.7 pounds per 1,000 filled bottles. The spiral conveyor had so steep a pitch to overcome the braking effect of its small circumference that the cases of filled bottles speeded down the spiral, bouncing over the rollers. In five cases of filled half-pint bottles which followed each other consecutively, 3, 7, 4, 2, and 3 bottles, respectively, were bounced out of place. Although the displaced bottles, being small and short, caught on the cross wires of the case and did not fall out, their bouncing out of place showed the severe jolting that bottles were receiving on this conveyor.

In another plant the presence of two concrete beams close together limited the diameter of the spiral conveyor to 5 feet. This small diameter, together with the fact that it was a smooth-slide conveyor rather than a roller-bearing conveyor, caused the cases to stick frequently. A hook on the end of a long pole was used to break up the jams and start the cases moving.

These facts show why plant managers should pay careful attention to the design and installation of spiral conveyors if they are to be used.

COMPARISON OF DIFFERENT METHODS OF GETTING BOTTLES TO WASHERS

The amount of glass broken in transferring bottles to the washers ranged from 32.0 to 44.7 per cent of the total breakage in 76 plants where four different systems were used for getting the bottles from the checking-in platform to the washers. (Table 9.) The four systems were as follows: (1) The washer was so near to the checking-in platform that a conveying system was not required; (2) conveyors were used with a minimum stacking of bottles; (3) trucks were used; and (4) conveyors were used with considerable stacking of cases. Only those plants where checking in, washing, and filling were all accomplished on one floor are included in this comparison.

TABLE 9.—*Comparison of bottle breakage when various systems were used in getting bottles to washer from checking-in platform*

System used for moving bottles	Plants	Bottles handled daily	Broken glass per 1,000 bottles handled		
			Breakage before washing	Total plant breakage	Breakage before washing, in percentage of total plant breakage
	Number	*Number*	*Pounds*	*Pounds*	*Per cent*
Direct transfer, with washer close to checking-in platform	15	16,140	2.4	7.5	32.
Conveyors used with some stacking of bottles	24	41,073	3.1	7.8	39.
Trucks used	12	26,948	4.9	11.5	42.
Conveyors used, with considerable stacking of bottles	25	50,794	5.9	13.2	44.

On an average, fewer bottles were broken before washing in those plants where the washer was located close to the checking-in platform. With this system very little handling of bottles is required, but of course its use is practicable only in the smaller plants.

The advantages of a good conveyor system are shown in the lower average breakage in the 24 plants which had well-arranged conveyors and required only a minimum amount of stacking of cases, as compared with that in the 25 plants where considerable stacking was necessary. In the latter plants the breakage before washing was not only greater but it represented 44.7 per cent of the total plant breakage, as compared with 39.7 per cent in plants in the former group.

The plants using well-arranged conveyor systems with a minimum amount of stacking also had a much lower breakage before washing and total breakage than the plants using trucks to transfer the bottles from the checking-in platform to the washers.

At the plants using trucks for this purpose, the handling of the cases of bottles in loading the trucks and the frequent rough handling of the truck loads of bottles resulted in greater breakage than at the plants using conveyors with a minimum of stacking. The breakage where trucks were used was, however, less than at the plants using conveyors with a large amount of stacking.

COMPARISON OF RESULTS WITH POWER-CONTROLLED CONVEYORS AND WITH GRAVITY CONVEYORS

In the foregoing comparison of methods of moving bottles to the washers, conveyor systems were classified on the basis of the amount of stacking or rehandling of cases required. In order to compare results with different types of conveyors, irrespective of the amount of rehandling of cases, 39 of the plants with conveyor systems were arranged in two groups. (Table 10.) The first group of 25 plants had long conveyors which depended solely upon gravity for moving the bottles to the washers. In the second group of 14 plants an electric switch at the washer enabled the operator to control the movement of cases over the conveyors, which included mechanical power boosters in addition to other lengths of gravity roller conveyors.

TABLE 10.—*Effect upon bottle breakage of type of conveyor used in moving bottles to washers*

Type of conveyor	Plants	Bottles handled daily	Glass broken per 1,000 bottles filled	
			Before washing	Total plant breakage
	Number	*Number*	*Pounds*	*Pounds*
Gravity conveyor used	25	53,979	6.5	14.6
Power conveyor, or gravity and power conveyor, with movement of bottles controlled by operator, usually at feed end of washer	14	64,892	3.6	9.5

The average breakage before washing was 6.5 pounds, and the total plant breakage was 14.6 pounds in the group of plants which depended upon gravity without control, as compared with 3.6

pounds and 9.5 pounds at corresponding points in the other group of plants which had the movement of cases controlled by electric switches at the washer.

At plants where the men putting the cases of bottles on the conveyor could control the flow of bottles to the washer, as in the case of a short conveyor, automatic control would not, of course, be necessary, and such plants were not included in the comparison.

The effect of the use of gravity conveyors as compared with power-controlled conveyors was also noticeable at the checking-in platform. In some plants where gravity roller conveyors extended at right angles to the side of the checking-in platform, some drivers would throw or slide the cases along the conveyor as far as possible to speed them up and to hasten unloading. This practice caused cases to bang against each other, and, furthermore, frequently a case would slide along the side rail and topple off on the floor. If a power-controlled conveyor were used, the cases would not be likely to bang and topple off.

COMPARISON OF RESULTS WITH VARIOUS TYPES OF CONVEYORS FOR MOVING BOTTLES LONG DISTANCES

On account of the more elaborate conveyor systems required in large plants, 16 of the larger plants where the bottles were transferred long distances were classified into three groups, according to the type of conveyor used. (Table 11.) Plants where the bottles were sent to the floors above the street floor are not included. In the first group gravity conveyors were used throughout, with booster sections where necessary to keep the bottles moving. In the second group gravity conveyors were also used, but at all points where the cases of bottles might come too fast or jam, switches were installed which were operated by electricity. When the conveyor became full of cases of bottles the switch would operate automatically and shut off the booster which brought the bottles up on the conveyor. When the bottles had passed on, this automatic stop would be released and permit more cases to come along the conveyor. This arrangement tended to prevent any jamming of the cases of bottles on the conveyor. In the third group of plants power conveyors were used.

TABLE 11.—*Comparison of bottle breakage when different types of conveyors were used for moving bottles long distances*

Type of conveyor	Plants	Glass broken per 1,000 bottles handled	
		Before washing	Total
	Number	*Pounds*	*Pounds*
Gravity	5	6.2	12.5
Gravity, equipped with automatic stops	4	2.6	7.4
Power	7	2.9	7.3

The breakage was the greatest when gravity conveyors without automatic control were used. There was very little difference in the results whether gravity conveyors equipped with automatic stops

or power-controlled conveyors were used. The data in Table 11 illustrate the importance of having gravity conveyors properly under control.

EFFECT OF SHARP CURVES AND TOO STEEP INCLINES

The paths that the bottles traveled from the checking-in platform to the milk-storage room differed widely in different plants. Some plants had been so laid out that the conveyors had many sharp curves and steep grades, so the course of the bottles was similar to that found on roller coasters or derby racers in amusement parks. Some other plants were so arranged that the bottles traveled through the plant more nearly as they would on a slow-moving miniature railroad. Sharp curves and steep grades were frequently the indirect as well as the direct cause of severe jolting and bumping of cases and breakage of bottles.

One cause of the high breakage in some plants was that there was a sharp curve at the top of a booster, as shown at *b* in Figure 1, A. Such curves exerted a braking effect on the cases when they arrived at the top of the booster *a*. This frequently caused cases to buckle up and bottles to fall out. When there was a few feet of straight conveyor (*d* to *e*, fig. 1, B) with a slight downward grade between the top of the incline and the curve, the cases gained enough momentum to offset the braking effect of the curve and carry them around the curve. This also increased the speed of the cases, moving them away from the top of the incline and preventing them from hampering the movement of other cases arriving at the top of the booster.

As an example of the relatively large amount of breakage due to having a sharp curve too close to the booster, in one plant the breakage of glass before washing amounted to 7 pounds per 1,000 bottles handled. The conveyor arrangement in this plant is illustrated in Figure 1, A. In this plant the cases of dirty bottles from the checking-in platform were elevated by a power conveyor to the second floor for stacking, washing, and filling. The power conveyor came through the second floor, as shown, and continued to elevate the cases of dirty bottles to point *a*, to provide for gravity acceleration to move the cases over the gravity roller conveyor toward the washers. The sharpness of the curve at *b* had such a braking effect on the cases as to slow them up, and frequently a case would stop at point *b*. Another case coming up the booster would not have enough momentum to move itself around the curve and start the first case. The result was that both cases would stop. The third case would also stop, causing the fourth case to buckle up, drop bottles out, and break them. The breakage here was caused by two factors: (1) The curve was too close to the booster; (2) the booster was so steep that it was easier for a case to buckle up than it was for it to push the line of cases around the curve.

The good effect of proper location of the curve at the head of the booster is illustrated in a plant which also elevated the dirty bottles to the second floor over a booster and then moved them at right angles, but with one important difference. This difference was that there was a few feet of straight conveyor between the top end of the booster and the curve (*d* to *e* in Fig. 1, B). The con-

veyor being straight where it joined the booster, the cases on reaching the straight section moved down freely by gravity alone and kept the head of the booster free from stalled cases. The pitch of the gravity conveyor was enough to slightly increase the momentum and

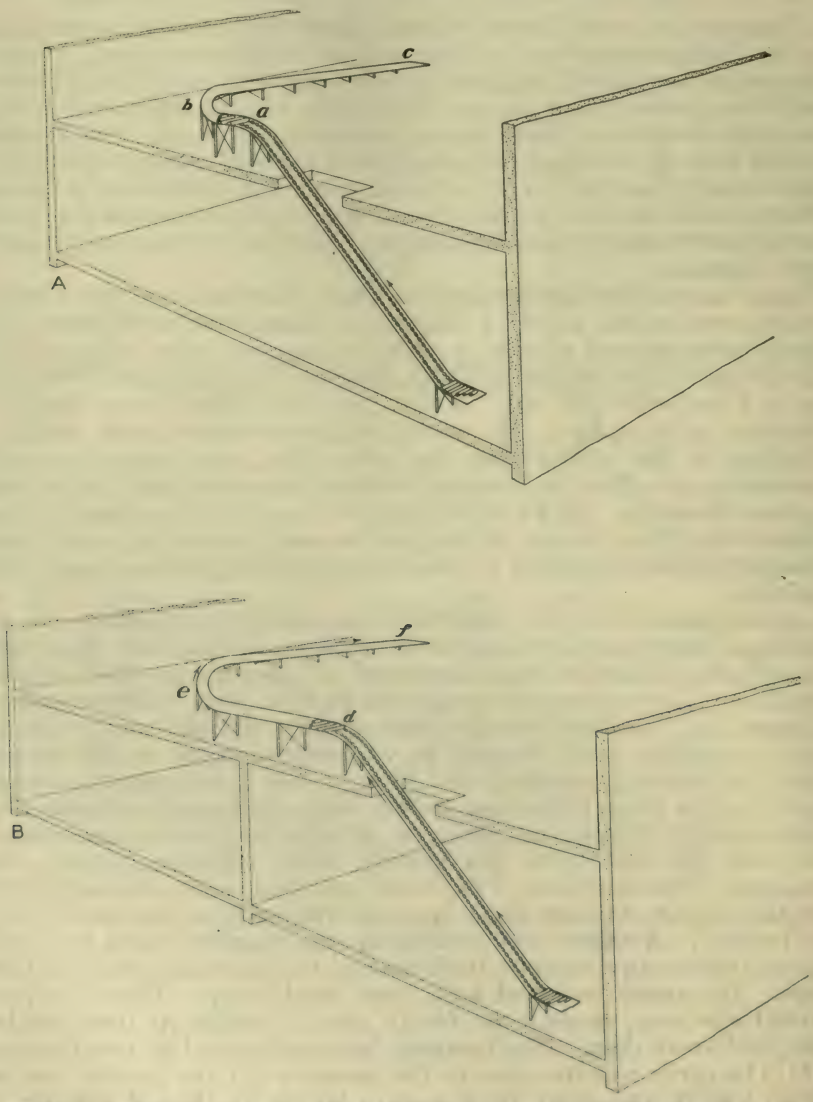

FIGURE 1.—Combination of a steep booster and gravity conveyor having a sharp curve: A shows an installation which frequently causes trouble, because the curve is too close to the top of the booster; B shows the better location of the curve

speed of the cases. This increase in momentum also helped to keep the head of the booster free and to carry the cases around the curve. Moreover, the curve was of large radius, which was another factor in allowing the cases to move slowly over the conveyors. This difference in the arrangement of the conveyors in the two

plants was reflected in the fact that only 2.9 pounds of glass per 1,000 bottles handled was broken before washing in the latter plant, as compared with 7.0 pounds in the former plant.

COMPARISON OF POWER AND GRAVITY CONVEYORS FOR MOVING FILLED CASES LONG DISTANCES TO MILK-STORAGE ROOM

The breakage from moving filled cases into the milk-storage room was observed in two groups of plants using principally power and gravity conveyors, respectively. (Table 12.) The plants in the first group used either long continuous power conveyors or long power conveyors with only short lengths of gravity conveyors for moving the filled cases from the fillers to the stacking space in the milk-storage room.

TABLE 12.—*Average breakage when long power and gravity conveyors were used in moving cases of filled bottles*

Kind of conveyor used	Plants	Bottles handled daily	Broken glass taken out in milk-storage room per 1,000 bottles handled
	Number	*Number*	*Pounds*
Continuous power	0	43,993	1.2
Gravity roller	4	51,129	2.5

Many plants used gravity roller conveyors for moving the cases from the fillers to the stacking space in the milk-storage room, but only those plants were included in the second group which moved the bottles exceptionally long distances over gravity conveyors, either with or without power boosters. At all the plants included in this comparison, the filling room and the milk-storage room were on the same floor level.

The average breakage of filled bottles taken out of the milk-storage room was 1.2 pounds per 1,000 bottles handled in the group which used nearly continuous power-conveyor systems for moving filled bottles long distances, as compared to 2.5 pounds in the group which mainly used gravity roller conveyors. This breakage includes all breakage resulting from transferring the filled bottles from the filling room to the point where the filled bottles were stacked in the milk-storage room, as well as breakage which resulted from handling the cases in stacking them and in taking them down from the stacks.

The power conveyors moved the filled cases slowly and without severe bumping of cases.

EFFECT OF CONVENIENCE OF CONVEYORS ON BREAKAGE

The manner in which conveyors were installed in relation to convenience of operation was an important factor in the rapidity of handling the cases and in the amount of breakage. The effect of

convenience of conveyors on breakage was shown particularly at the checking-in platform and in the stacking room.

Table 13 compares the breakage before and after washing in two groups of plants with respect to convenience at the checking-in platform. The first group was made up of plants where the conveyors were conveniently arranged for the men loading and unloading cases. The plants in Group 2 had conveyors which were not convenient and handy for loading and unloading.

TABLE 13.—*Average breakage in two groups of plants with convenient and inconvenient arrangements of conveyors at checking-in platform*

Arrangement of conveyors	Plants	Bottles handled daily	Glass broken per 1,000 bottles handled	
			Before washing	Total plant breakage
	Number	*Number*	*Pounds*	*Pounds*
Group 1: Conveyors convenient and handy for loading and unloading	23	47,282	3.0	8.4
Group 2: Conveyors not convenient or handy	12	40,494	7.6	15.6

The average breakage before washing in the plants in Group 1 having conveniently arranged conveyors was 3.0 pounds, as compared with 7.6 pounds in the plants in Group 2. In many of the plants in Group 1 the conveyors extended close enough to the wagons or trucks and were of such height that the drivers, when standing in or beside their wagons, could set the cases on the conveyors with little movement and only slight clicking of the bottles in the cases. Two of the plants had movable roller conveyors which could be extended into the larger trucks. These conveyors were easy to move and enabled the driver to place the cases directly on the conveyor as he worked toward the forward end of the truck in unloading.

In one of the plants in Group 2 the conveyor was located so far from the edge of the checking-in platform that an extra man was required to transfer cases to the conveyor. In the rush of unloading he did not have time to take the step or two necessary to place the cases on the conveyor, so he tossed them on, some cases striking very hard and breaking bottles. If the conveyor had been closer to the edge of the platform this banging of cases and breakage would have been less. This same condition was found in another plant where the usual practice was to throw or toss the cases onto the conveyor. Frequently a case would topple over and the bottles would fall out. In some plants the conveyors were so high that the drivers had to throw the cases up to the conveyors or have an extra man to help unload.

The effect of convenience on breakage of bottles was shown also in the arrangement of conveyors in the stacking room, or wherever the men had to load cases on or take them off the conveyors. In some of the plants in Group 2 the conveyors were so close to the floor that the men had to bend their backs to set the cases on. The natural and more common practice was to drop the cases onto the conveyor with a bang. This jolted and jarred many bottles, the bottles some-

times striking against each other, especially in worn cases having loose cross or bottom wires.

The arrangement of conveyors with reference to the size and shape of stacking space was also a factor in the breakage of bottles. In one plant the stacking room for bottles was nearly square, with the main conveyor near one side. When the room was full of stacked cases, a man tossed the cases upon the conveyor, gradually working farther away from the conveyor until the distance was so great that an extra man was required to pass the cases along.

Plant 326 in this study was a well-arranged and well-equipped milk plant. The ground-floor plan of this plant is shown in Figure 4 (p. 26). In this plant the stacking spaces and conveyors were well arranged for moving and stacking dirty bottles before washing. Each stacking space was rectangular in shape rather than square, and the conveyors were convenient to all sections of the stacks, so that in no place were the cases carried long distances by hand.

EFFECT OF CONDITION OF CONVEYORS IN MILK-STORAGE ROOM ON BREAKAGE

The condition of the conveyors in the milk-storage room was a factor in the breakage at that point. This is shown in Table 14.

TABLE 14.—*Effect of condition of conveyors on amount of broken glass taken out in milk-storage room*

Condition of conveyors	Plants	Bottles handled daily	Broken glass taken out of milk-storage room per 1,000 bottles handled
	Number	*Number*	*Pounds*
Group 1: In good repair and well lubricated, with live, free-running rollers	6	21,024	0.7
Group 2: Had worn bearings and depressed and sluggish rollers	5	42,254	2.6

There was less bumping and jolting of cases, and consequently less breakage of bottles, on gravity conveyors which were kept well lubricated and in good repair than on conveyors which had worn and depressed bearings and those which had sluggish rollers. Poor condition of the rollers oftentimes was due to lack of frequent and regular lubrication and failure to keep the conveyors in first-class repair.

In one plant in Group 1 in Table 14, when a length of conveyor began to show signs of needing repair, even if it was not expected to break down immediately, it was taken out at once and another conveyor which had been previously repaired and held in reserve was put in its place.

EFFECT OF HANDLING UPON BREAKAGE

A study was made to determine how much more breakage there was in plants which required much handling of bottles than in plants so arranged and equipped that handling of bottles by employees was reduced to a minimum. At the 22 plants comprising Group 1 in

Table 15 a large amount of handling was required to move the bottles in the plant from the checking-in platform through to the milk-storage room and out again. At the 18 plants in Group 2 in Table 15 a small amount of handling was involved.

TABLE 15.—*Effect upon breakage of number of times bottles are handled*

Amount of handling	Plants	Bottles handled	Glass broken per 1,000 bottles handled	
			Total before washing	Total plant breakage
	Number	*Number*	*Pounds*	*Pounds*
Group 1: Plants which had considerable handling of bottles	22	46,155	7.0	16.7
Group 2: Plants which had very little handling of bottles	18	36,176	3.4	1

It will be noted that the total plant breakage in Group 1 was 7.6 (16.7−9.1=7.6) pounds (or 83 per cent) greater than that in Group 2. The largest percentage increase between the two groups at any one point occurred before washing, where the amount of handling was greatest. At this point the breakage in Group 1 was 3.6 pounds or 106 per cent greater than that in Group 2.

One way in which bottles are broken in handling is shown in Figure 2, A. In stacking cases some men rest the case on its front edge *a*, on top of the stack, with the rear side raised at a wide angle. The man then lets go of the case, letting it flop into place. This flopping through a wide arc, *b*, and the subsequent jolt often cause the bottles to strike sideways forcibly enough to crack and break. As cases of filled bottles come down with a hard jolt—and bottles filled with milk will strike more forcibly than empty bottles—even greater care should be exercised when stacking filled cases. A quart bottle of milk weighs 3.7 pounds, and a filled case between 60 and 65 pounds, so even a short drop may break the glass.

The tendency for empty bottles to break when cases are allowed to flop over in stacking (as in figure 2, A) is also greater when the bottles are inverted in the cases, as at plants where in-the-case washers are used and the washed bottles are stacked for cooling before being filled. Some bottle cases do not prevent bottles from striking together when they are inverted in the cases, and frequently bottles are cracked if the cases are not handled carefully when stacked.

Figure 2, B, shows a man stacking cases carefully. He is holding the case of bottles in a nearly level position as he sets its front edge down on top of the stack, *c*. If he then lets go of the case while it is in this position its rear side will drop only an inch or two at most, and in a nearly vertical direction, without flopping and with only slight jarring of the bottles.

COMPARISON OF BREAKAGE WHEN DIFFERENT SYSTEMS OF WASHING AND FILLING BOTTLES WERE USED

A study was made to compare the effect which the direct, indirect, and semidirect systems of washing and filling bottles had on break-

age. The direct system refers to the use of the soaker type of washers which cool the bottles in the machine and from which they go directly to the fillers. With the indirect system the bottles are washed in the cases in a pressure washer and then stacked for cooling, and later they are taken down from the stacks and transferred to the fillers. The semidirect system is similar to the indirect, with the exception that the bottles are cooled by sprays of cold water in

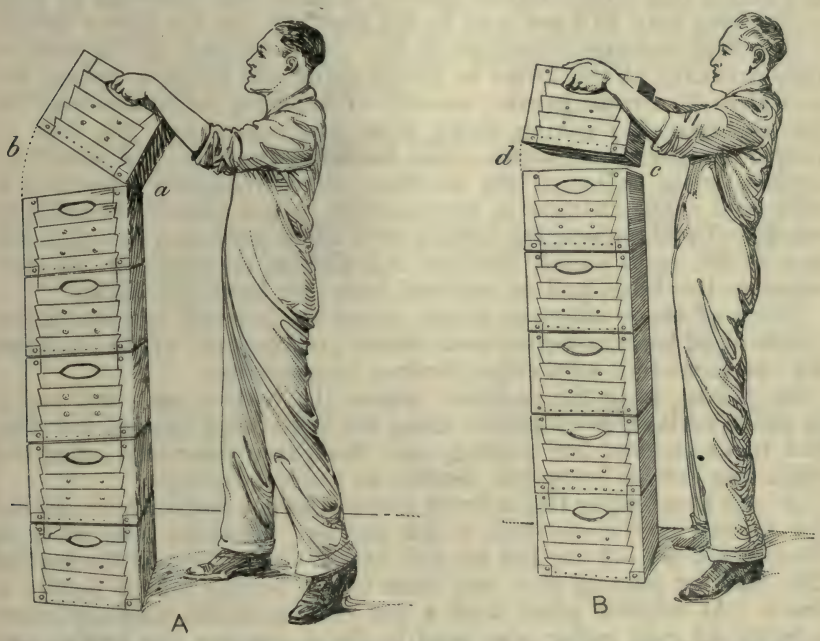

FIGURE 2.—Two ways of stacking cases of bottles. In A the rear side of the case will flop through a wide arc and bottles may get cracked or broken; in B the bottles even with rough handling are less likely to get cracked or broken

passing through the machine and move directly to the fillers from the bottle washers. A comparison of the breakage in these three systems is shown in Table 16.

TABLE 16.—*Breakage of bottles in milk plants using the direct system as compared with the indirect and semidirect systems*

System used	Plants	Bottles handled daily	Broken glass taken out per 1,000 bottles handled			Breakage at discharge end of washers plus breakage at fillers, in percentage of total plant breakage
			Before washing	At discharge end of washers and at fillers	Total plant breakage	
	Number	*Number*	*Pounds*	*Pounds*	*Pounds*	*Per cent*
Direct	95	54,448	4.8	5.8	11.8	49.2
Indirect	21	41,567	4.5	7.8	13.6	57.4
Semidirect	4	45,383	4.0	9.4	15.2	61.8

The average amount of broken glass taken out at the discharge end of the washer and at the fillers was 5.8 pounds per 1,000 bottles handled where the direct system was used, as compared with 7.8 pounds in those plants using the indirect system. This latter breakage is 34.6 per cent greater than that at the plants using the former system. The breakage at the discharge end of the washer plus breakage in the fillers was 57.4 per cent of the total plant breakage in the plants using the indirect system, whereas the breakage at these points was only 49.2 per cent in the plants using the direct system.

The high average breakage at the discharge end of the washers plus breakage at the fillers in plants using the indirect system was doubtless due to the greater amount of handling of bottles required for stacking and taking down from the stacks and the lack of proper temperature control. The bottles washed by the semidirect system, being cooled in the machine, were frequently subjected to wide and rapid changes in temperature, which caused temperature cracks. Furthermore, the bottles were often subjected to bangs and jars as the cases passed through the washer, traveling on the conveyor to the filler, and in removal from the cases for filling.

Many of the washers in plants using the indirect and semidirect systems had been in service many years, and on many of the machines the thermometers were either broken or inaccurate.

In plants using the indirect system the bottles were not cooled in the machines, as in plants using the semidirect system, but they had to be stacked for cooling, and this extra handling, especially while the bottles were hot, tended to cause breakage.

At one plant using the indirect system the hot bottles were stacked for cooling in a room with a low ceiling. Exhaust fans were installed to draw out the hot air and hasten the cooling of the bottles. The cold air passing over and close to the bottles caused bottles to crack. At another plant with a low ceiling in the stacking room, a spray of cold water was used to finish cooling the bottles just before they went to the filler. A considerable proportion of the broken bottles taken out before going to the fillers had been cracked seemingly by temperature changes.

The breakage due to stacking hot bottles was partly due to the bottles being inverted in the cases. Cases are designed with cross-pieces spaced primarily to keep bottles from striking against each other when upright in the case. In plants using the in-the-case washers, the bottles were placed in the case upside down, and often the cases would not prevent the bottoms of the inverted bottles in them from striking together and cracking when the bottles were stacked for cooling.

The chances for hot inverted bottles to strike together with sufficient force to break them is greater in plants where the cases are stacked higher than the men can reach easily.

EFFECT OF TEMPERATURE ON BREAKAGE

With the direct system of washing and filling bottles, at some plants high temperatures are used to kill bacteria, while at other plants chemicals are used and the temperature of the rinsing water

is lower. Usually fewer bottles are broken when the temperatures are not so high or the temperature changes so great.

At nine plants the treatment to kill bacteria was changed from heat treatment to chlorine treatment. Records were obtained on the breakage at these plants before the change was made and after it was made. Table 17 shows that seven of the nine plants had less breakage after changing over to the chlorine treatment. The total decrease for all of the seven plants was 1,921 pounds per day, which is equivalent to a total yearly decrease of 701,165 pounds, or approximately 539,196 bottles. This number represents an average annual saving per plant of 77,028 bottles.

TABLE 17.—*Breakage of bottles in nine milk plants when using heat treatment and when using chlorine treatment to kill bacteria*

Plant No.	Bottles handled daily	Broken glass at discharge end of washer and at filler, per 1,000 bottles handled		Plant breakage per 1,000 bottles handled		Difference in plant breakage [1]	
		Heat treatment	Chlorine treatment	Heat treatment	Chlorine treatment	Per 1,000 bottles handled	Per day
	Number	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1	29,344	8.2	6.8	19.0	9.9	−9.1	−264
2	46,300	6.4	10.6	25.6	18.6	−7.0	−324
3	38,889	4.5	4.2	13.6	11.9	−1.7	−66
4	46,727	6.8	3.4	19.0	14.5	−4.5	−210
5	100,843	8.0	2.4	16.6	14.6	−2.2	−221
6	132,916	5.3	8.5	12.3	12.8	+0.5	+66
7	82,137	7.8	5.1	22.9	21.4	−1.5	−123
8	59,152	7.4	10.6	18.5	24.0	+5.5	+325
9	75,068	9.5	4.6	25.6	16.1	−9.5	−713
Total for plants showing decrease							−1921
Total for plants showing increase							+391

[1] It is not assumed that this difference was entirely due to the change from heat treatment to chlorine treatment, with lower temperatures, but this change was one of the important factors.

Although these nine plants effected savings in different ways at different points in the plant, the use of treatment with chlorine solutions in place of treatment with hot water apparently reduced the breakage due to sudden changes in temperature in most of the plants. When these plants were using the heat treatment, they treated their bottles with hot water at 180° F., or higher, and then cooled them down quickly to 45° or below before filling. Cooling the bottles so rapidly over such a wide range of temperature put them under a severe strain. When there was a change in the pressure of the steam used to heat the water, or in other conditions which caused sudden changes in the temperature of the washing, treating, or cooling water, many bottles were cracked before the proper temperatures could be reestablished.

EFFECT OF CONDITION AND TYPE OF CASES ON BREAKAGE

The function of a case is not only to hold up the weight of the bottles and contents but also to cushion the bottles from jolts and jars. Worn cases oftentimes failed to protect bottles against break-

age. In stacking cases, sagging bottoms cause breakage by permitting bottles to strike the tops of bottles in the case beneath. Sagging bottoms are especially hard on filled bottles, both in stacking cases and when the cases travel over conveyors not in good condition. A worn case with a sagging bottom might have enough resilience left to carry empty bottles over an uneven conveyor without their striking on the rollers; whereas filled bottles, especially the larger sizes, would receive blows hard enough to crack them.

Various types of cases used also differed somewhat in the protection they afforded bottles against striking each other sideways. The crosspieces should protect bottles from cracking or breaking by absorbing shocks instead of transmitting them. In some kinds of cases, this cushioning effect on bottles was effected by the position and number of cross wires or pieces between the bottles; in others, by metal crosspieces shaped to cushion the bottles against blows; and in still other cases, by wooden crosspieces with grooves for the bottles. However, as a rule the condition of the case seemed to have more effect than the design of the case in protecting the bottles from breakage.

Protection of bottles from breaking is as important a function of a case as is that of holding bottles for ease in handling. But through wear or rough handling, cases frequently failed to protect bottles adequately, long before their condition made it impossible for them to hold bottles. In many plants breakage of bottles in the cases was due in large part to the common practice of not repairing or discarding a case until the handles broke out or until protruding or bent wires obstructed the movement of cases on conveyors.

Sharp curves on conveyors wore the cases on the corners. Also, moving filled cases around sharp curves, and the practice common in some plants of throwing and dropping cases so they landed on an edge or corner tended to force some of the cases out of shape. Although many of the cases were well designed and constructed, they could not be expected to properly protect the bottles and contents under this kind of rough treatment.

BREAKAGE IN MILK-STORAGE ROOM

The breakage of filled bottles being transferred from the fillers to the milk-storage room and being handled in the milk-storage room, has been mentioned previously. (See Tables 7, 8, 12, and 14.) The amount of glass broken in these operations, as taken out in the milk-storage room, is reported here separately because of its importance. Breakage of bottles at the fillers and in transferring to and handling in the milk-storage room resulted in the loss of at least a part if not all of the contents in addition to the bottle itself. Even when the contents were not entirely lost, additional expense and labor were required to handle the milk. The breakage due to these causes in 116 plants are shown in Table 18.

TABLE 18.—*Range in breakage of bottles in milk-storage room in 116 plants, in pounds of broken glass per 1,000 bottles handled, showing the low breakage in some plants as compared with others*

Range (pounds)	Plants	Range (pounds)	Plants
	Number		*Number*
0.5 or less	27	3.1 to 3.5	5
0.6 to 1.0	37	3.6 to 4.0	1
1.1 to 1.5	24	4.1 to 5.0	(1)
1.6 to 2.0	9	5.1 to 5.5	1
2.1 to 2.5	7	5.6 to 7.5	(1)
2.6 to 3.0	4	7.6 to 8.0	1

[1] There were no plants falling within the ranges of 4.1 to 5.0 pounds, and 5.6 to 7.5 pounds.

At 64, or more than half, of the 116 plants the breakage did not exceed 1 pound per 1,000 bottles handled; at 33 it ranged between 1 and 2 pounds; at 11 it was 2 to 3 pounds; and at 8 it was 3 to 8 pounds. Of the 64 plants with low breakage, 37 were in the group where it was 0.6 to 1.0 pound, and 27 plants were in the group where the breakage was 0.5 pound or less; moreover, in the latter group there were 3 plants which had only 0.1 pound of breakage, 5 which had 0.2 pound, and 8 which had 0.3 pound. These facts show that with the exercise of reasonable care it is entirely practical to have a low breakage in the milk-storage room.

In one plant the low breakage in the milk-storage room was attributed to the plant's having plenty of floor space, so that it was necessary to stack the cases only six cases high. Stacking six cases high for quarts and seven cases high for pints made it easier to stack the cases and to take them down, and low breakage resulted. In some plants, during the rush of loading out in the morning, the men had to work fast and where cases were stacked higher than a man could reach conveniently, accidents caused considerable breakage.

COMPARISON OF NUMBER OF BOTTLES BROKEN, BY SIZES

At 69 plants the breakage of bottles of the various sizes was kept separate. The order of the breakage by sizes of bottles, expressed in number of bottles broken per 1,000 bottles handled, is shown in Table 19.

TABLE 19.—*Order of breakage of bottles by sizes at 69 plants*

Order of breakage [1]	Plants	Percentage of total plants
	Number	*Per cent*
Quarts, jars, pints	19	27.5
Jars, quarts, pints	17	24.6
Quarts, pints, jars	14	20.3
Pints, quarts, jars	11	16.0
Jars, pints, quarts	6	8.7
Pints, jars, quarts	2	2.9
Total	69	100.0

[1] By order is meant the highest, second highest, and third highest number of bottles broken per 1,000 handled; for example, "Quarts, jars, pints" means that the breakage of quart bottles was the highest and the breakage of pint bottles was the lowest.

It will be noted that the most common order was (1) quarts, (2) jars (bottles less than 1 pint in size), (3) pints; and the second most common order was (1) jars, (2) quarts, (3) pints. The order (1) pints, (2) jars, (3) quarts was the least common, there being only two plants in this group.

For all 69 plants the average breakage of bottles by sizes was highest for quarts and lowest for pints. The average breakage of quarts was 9.6 bottles per 1,000 quart bottles handled; that of pints was 7.2 bottles per 1,000 pints handled; and that of jars, 8.1 per 1,000 jars handled.

As before stated, this study was made in selected plants with different layouts and systems in order to show the effect of plant arrangement on breakage of bottles; therefore, the average breakage for these plants can not be said to represent the average breakage for all plants. However, the data presented in Table 19 roughly indicate the relative breakage of the various sizes of bottles at the average plant. The data indicate that as a rule the breakage of quart bottles usually is the highest, and that more jars will be broken in proportion to the number handled than pints. Usually a quart bottle will break easier than a smaller bottle when subjected to the same blow. Furthermore, in the bottles that were examined, more temperature cracks were found in quart bottles than in the smaller bottles. Likewise, pint bottles probably will break more easily than half-pint bottles when subjected to the same blow. The small-sized bottles (one-half pint, one-third quart, and one-fourth pint) are, however, subjected to more blows and strains in the average milk plant than the larger bottles (pints and quarts). When cases are traveling on gravity conveyors or on escalators, the smaller bottles are bounced out of the cases more readily than are the larger bottles. While in the washing machines, the smaller bottles tend to receive more jolts and blows than the larger bottles, as these machines are designed primarily for bottles of quart and pint size. At the fillers a large proportion of the small-sized bottles are filled with cream, and in bottling cream small bottles sometimes stick to the valves of the filler after the valves are released and get knocked off the bottle carrier. Also, the smaller bottles, on account of their small diameter, show a greater tendency to topple over and slide off the bottle carriers of the filler. This tendency is aided by leaking valves, which permit cream to escape on to the carrier or platform of the filler, thereby causing jars to slide off the carrier or platform as it is raised to bring the bottles into contact with the valves for filling.

BREAKAGE IN SMALL PLANTS

Conditions found in small plants were frequently different from those observed in medium-size and large plants. The breakage in the 23 plants handling fewer than 10,000 bottles daily is shown separately from the breakage in the 121 plants of medium to large size in Table 20.

TABLE 20.—*Comparison of the breakage of glass at different points in large versus small plants*

[Breakage is shown in number of pounds of broken glass per 1,000 bottles handled]

Breakage	Plants handling from 10,000 to 100,000 bottles daily (average for 121 plants)	Plants handling less than 10,000 bottles daily (average for 23 plants)	Difference
Breakage before washing:	*Pounds*	*Pounds*	*Pounds*
At receiving platform, including breakage of bottles resulting from unloading the wagons and dumping returned milk	1.7	1.0	0.7
At feed end of washer	3.0	1.5	1.5
Total	4.7	2.5	2.2
Breakage in washing and filling:			
At discharge end of washers	2.6	1.8	0.8
At fillers	3.9	2.2	1.7
Total in washing and filling	6.5	4.0	2.5
Breakage in milk-storage room, including breakage in transferring filled bottles to storage, stacking, and loading out at checking-out platform	1.2	0.6	0.6
Total plant breakage	12.4	7.1	5.3

The average breakage in the 23 small plants was 7.1 pounds per 1,000 bottles handled, or nearly 43 per cent less than the average breakage for the medium-size and large plants. The figures for the breakage in different parts of the plants show that small plants broke fewer bottles at all points than the medium and large plants.

Low breakage depended more upon the arrangement of the plant and the kind and condition of the equipment than upon the size of the plant. However, plants handling a small number of bottles were more inclined to have plant conditions favorable to low breakage than was always possible in plants of medium or large size. For example, many of the small plants, because they were small, had the feed end of the washer located only two or three steps from where the wagons were unloaded. The bottles were stacked close to the washer and neither conveyors nor other equipment was required to move them to the washer. In small plants, as a rule, bottles did not travel as far as in larger plants, and the number of feet of conveyors or other equipment to keep in condition was less. In small plants, the manager or superintendent, in addition to supervising the operations, frequently worked with the other employees, and all employees would naturally exercise more care. Small plants handled fewer bottles and consequently when a bottle was broken it was more noticeable and not regarded as a passing incident as breakage was sometimes considered in some larger plants.

WHEN IS BREAKAGE HIGH OR LOW?

Various factors may affect the amounts of breakage. Some of the more important factors which have a direct effect on the quantity of glass broken, as previously brought out, as are follows: General arrangement of plants; arrangement of equipment in plants;

types of equipment; care and condition of equipment; changes in temperature to which bottles are subjected, care in handling bottles; and the quality of the glass of which the bottles are made.

The total plant breakage showed the combined effect of all these factors. (Table 21.)

TABLE 21.—*Classification of 121 milk plants according to number of plants falling within the various ranges of total plant breakage*

	Number of plants having a breakage per 1,000 bottles handled of—							
	5 pounds or less	5.1 to 7 pounds	7.1 to 10 pounds	10.1 to 13 pounds	13.1 to 16 pounds	16.1 to 19 pounds	19.1 to 22 pounds	22.1 pounds or higher
Number of plants	4	11	26	34	20	16	6	4
Average pounds broken	4.2	6.1	8.5	11.6	14.5	17.4	20.1	26.6

In 41, or 34 per cent, of the 121 larger plants studied the average breakage did not exceed 10 pounds. Thirty-four other large plants, or 28 per cent, averaged between 10.1 and 13 pounds. Therefore, in 75 plants, or 62 per cent of the 121 plants, the plant breakage did not exceed 13 pounds per 1,000 bottles handled.

At these 121 plants, on an average, 39 per cent of the total breakage in the plant occurred before washing. Fifty-two per cent of the broken glass was collected at the discharge end of the washer and at the fillers, and the remaining 9 per cent of the breakage was taken out in the milk-storage room. Breakage from chipped bottles, as a rule, was not included in the above figures for plant breakage, because most of the chipping occurred while the bottles were away from the plant. As stated on page 2, the breakage from chipped bottles amounted to about 25 per cent of the total breakage, and the breakage in the plant represented the remaining 75 per cent.

COMPARISON OF TWO MILK PLANTS

A medium-sized plant, called plant 321 in this study, was an old, poorly arranged plant which had been enlarged one or more times. Another plant, 326, was a new, well-arranged and well-equipped plant. The floor plans of these two plants are shown in Figures 3 and 4.

In plant 321 many of the conditions prevailed which had been found to cause high breakage of bottles. Plant 326 had most of the features which were found to contribute to keeping the rate of breakage low.

Plant 321 handled 42,227 bottles daily. The plant breakage averaged 27 pounds per 1,000 bottles handled. The poor arrangement of this plant was due in part to enlargements which had been made in order to increase capacity.

The high breakage was due to a number of conditions, some of which are apparent from the plan shown in Figure 3. The bottles had to travel longer distances in all parts of the plant than would have been necessary if the plant had been well arranged. Traveling long distances does not necessarily cause bottles to break if they are moved carefully and with a minimum of handling.

AN OLD, POORLY ARRANGED PLANT

In this plant there were long lengths of gravity conveyors without control. This permitted cases to bang against each other. For example, after being unloaded from the wagons, the cases of dirty bottles traveled down a fairly steep gravity conveyor, frequently striking the cases at the lower end of the conveyor. Also, every case had to be taken off the conveyor and stacked before washing. The broken glass taken out before washing amounted to 9.3 pounds per 1,000 bottles handled.

In this plant the bottle-washing room was separated from the bottle-filling room by a can-washing room and a covered yard. Instead of being moved over continuous power conveyors controlled by switches, as in some plants where bottles are moved long distances, the cases of clean bottles were moved over gravity roller conveyors without control. Two separate boosters were required to move the cases of clean bottles through to the filling room. The conveyors were old and not in good repair. Also, turns in the conveyors

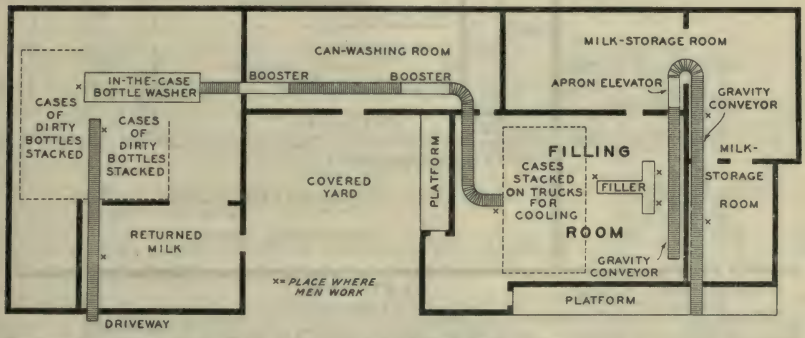

FIGURE 3.—Floor plan of an old, poorly arranged milk plant which had been enlarged one or more times

hindered the continuous and smooth movement of the cases of hot bottles.

An in-the-case washer was used, and the hot bottles had to travel by conveyor from the washer room the full length of the can-washing room and into the filling room. Here the cases were stacked on trucks and allowed to cool before being filled.

The 12.4 pounds of breakage at the discharge end of the washer and at the fillers was due to the extra handling required by the indirect system of washing and to the long distance the bottles were conveyed over gravity conveyors in poor condition, which was responsible for much bumping and banging of cases. Temperature cracks caused in washing represented part of the large breakage at this point.

The milk-storage room was irregular in shape and so located with reference to the filling room that the filled cases had another long distance to travel. The breakage of 5.3 pounds of glass in the milk-storage room shows the effect of the long, poorly arranged gravity conveyors, and extra handling. These conveyors were not kept in good repair. The filled bottles traveled into the milk-storage room in one direction and then completely reversed the direction by making a U turn and went out of the milk-storage room over a path parallel to the path of entrance.

Furthermore, at some places in the milk-storage room the conveyor was not located conveniently, and at these places the men had to carry the cases of bottles by hand some distance to stack them and back to the conveyors again when loading out.

The amount of handling of bottles in this plant was much greater than in well-arranged and well-equipped plants. Every case of empty dirty bottles had to be stacked or handled before it went to the washer. After being washed the cases of clean bottles were handled three times in the filling room, once in being stacked on trucks [2] for cooling, again in being removed from the trucks, and a third

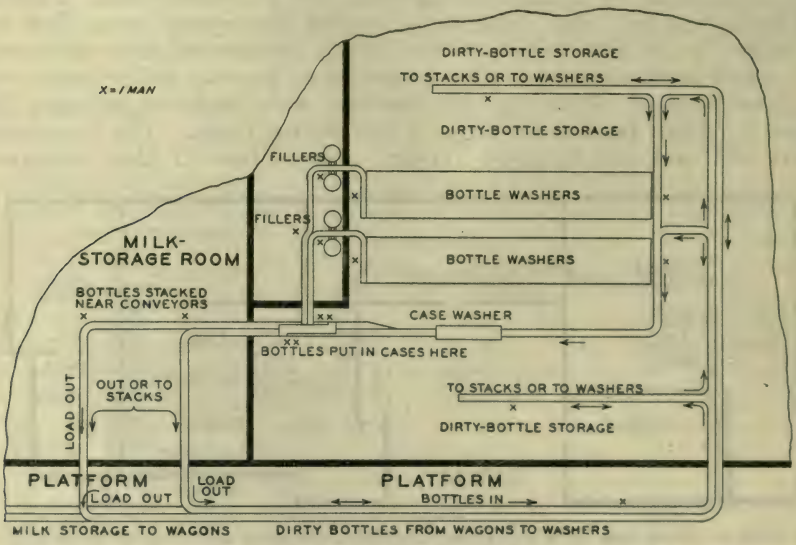

FIGURE 4.—Floor plan of a well-arranged and well-equipped milk plant

time in being inverted on the filler table preparatory to being filled. Also, considerable handling of cases was necessary in the milk-storage room.

A NEW, WELL-ARRANGED PLANT

Plant 326 handled 44,208 bottles daily. The total plant breakage was only 9.7 pounds per 1,000 bottles handled. The floor plan of this plant is shown in Figure 4. This plant and plant 321 were similar in one respect—both plants checked in the dirty bottles and loaded out the filled bottles on the same side of the building. But the two plants were different in many other respects. This plant occupied but little more floor space than the other plant, but it was so arranged and equipped that it could handle more than twice as many bottles, whereas plant 321 was already operating above its normal capacity. These two plans show the importance of plant arrangement in getting the largest output from the space and equipment provided, as well as in keeping the bottle breakage at a low point.

In plant 326 the cases of empty dirty bottles were unloaded directly onto a constantly moving conveyor which moved them slowly but continuously. The bottles were moved carefully and were not jolted

[2] The bottles were stacked in an inverted position in the cases.

nor banged together in the cases, as they frequently are when cases race down a conveyor and strike the line of cases near the lower end of the conveyor. Electric switches were located at convenient points so that the conveyors could be stopped at any time. Most of the dirty bottles went directly from the wagons to and through the washers, the only bottles stacked being those received before the washers were started, and the surplus bottles.

The bottles were washed in soaker-type washers and traveled directly to the fillers over mechanical conveyors. The filled bottles were then placed in cases and conveyed over power conveyors directly to the milk-storage room.

The average breakage at the discharge end of the washers, plus breakage at the fillers, was 4.0 pounds per 1,000 bottles washed, as compared with 12.4 pounds in plant 321, where the bottles were washed in an in-the-case washer and the hot bottles were moved over uncontrolled gravity conveyors in poor condition, to the filling room and there transferred to trucks, where they remained stacked for cooling before being filled.

SUMMARY

The bottle breakage in the plants studied depended to a large degree on the plant arrangement and on the equipment used.

Chipping of bottles caused many bottles to be discarded. A large proportion of this chipping occurred on the routes and especially on those routes having wholesale deliveries.

The size of the plant, in itself, was not a factor in the amount of breakage.

There was little relation between the distance the bottles traveled in the plant and the breakage.

There was a close relation between the number of transfers from floor to floor and the amount of breakage. Where the bottles were sent to an upper floor to be washed, both the breakage before washing and the total breakage were greater than where the bottles were washed on the ground floor or in the basement, if in the latter case the bottles were delivered to the ground floor by the washer itself. As a rule, at plants where bottles were moved to the basement to be washed the breakage was greater where gravity conveyors were used than where the transfer was made by power-controlled conveyors. Where the filled bottles were transferred to the milk-storage room on a floor below, the breakage in the milk-storage room was greater than where both the filling room and the milk-storage room were on the street floor and there was no transfer between floors. At the plants which had the milk-storage room on a floor below the filling room the breakage was greater where the transfer was made over straight or spiral gravity conveyors than where the transfer was made over power-controlled conveyors.

Both the breakage before washing and the total breakage were greater where trucks were used to transfer the bottles from the checking-in platform to the washer than where conveyors were used to make the transfer and there was a minimum of stacking of the bottles. Where the bottle washer was located close to the checking-in platform the breakage was less than where conveyors were used. At plants so arranged that there was a large amount of stacking of the bottles from the conveyors, the breakage was greater than at the plants at which the bottles were transferred by trucks.

When cases of bottles were transferred for considerable distances on conveyors, the breakage was greater at the plants using gravity conveyors than at those where power conveyors were used. However, where gravity conveyors were used, if these conveyors were equipped with automatic stops at points where jamming of cases was most likely to occur, the breakage was as low as where power conveyors were used. Steep inclines and sharp curves on gravity conveyors tended to result in higher breakage. The breakage was greater at the plants where gravity conveyors were used to move the filled bottles considerable distances to the milk-storage room than where power conveyors were used.

Where the conveyors were installed so that they were convenient for the men the breakage was less than where they were not convenient. The effect of convenience of conveyors on breakage was particularly marked at the checking-in platform and in the stacking room for empty bottles.

Keeping the conveyors in the milk-storage room in good repair and well lubricated was an important factor in holding down the breakage at that point.

Plants so arranged or so equipped that much handling of bottles was necessary had larger breakage than did those plants so arranged that only a minimum amount of handling was necessary.

At plants using the direct system of washing and filling bottles, both the total breakage and the breakage at the discharge end of the washers and at the fillers were less than at the plants using the indirect or semidirect systems. The breakage with the semidirect system was greater than with the indirect system.

Wide and rapid changes in temperature were important factors in breakage.

Worn cases with slack cross wires and sagging bottoms caused some breakage, especially in plants where the handling of cases, either by equipment or by men, was rough.

There was considerable variation in the amount of breakage in the milk-storage room. Many plants, however, had comparatively low breakage at this point, indicating that it is possible for a plant to be so arranged and equipped that breakage at this point can be kept down.

The relative amount of breakage of bottles by sizes was in the order of quarts, jars, and pints.

In the small plants studied the breakage was, as a rule, lower than in the large plants. This is attributed to the fact that plants handling fewer than 10,000 bottles daily do not require an elaborate system for transferring bottles from place to place, and conditions which tend to cause high breakage are not so likely to be present in them.

Although the human element is an important factor in any plant operation, and this is especially true in regard to care in handling bottles, it has been found that plant arrangements and types of equipment have an important influence on breakage of bottles, and the above factors were found to be the most important.

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Bureau of Dairy Industry	O. E. REED, *Chief.*
Division of Market-Milk Investigations	ERNEST KELLY, *Senior Market-Milk Specialist, Chief.*

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UNITED STATES DEPARTMENT OF AGRICULTURE
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CORRELATION OF HEREDITARY AND OTHER FACTORS AFFECTING GROWTH IN GUINEA PIGS

By ORSON N. EATON, *Associate Animal Husbandman, Animal Husbandry Division, Bureau of Animal Industry*

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INTRODUCTION

In previous studies of inbreeding in guinea pigs, Wright (*17*)[1] has discussed its effects on litter size, frequency of litter, weight at birth and weaning, and gain between birth and weaning. He has shown that high correlations exist between litter size and birth weight, birth weight and weaning weight, frequency of litter and litter size, and various other factors. Neither the variations in these correlations among the different inbred and control lines of guinea pigs have been shown, nor the correlations between early weights and gains and those after weaning. This bulletin shows the correlations which exist among several factors influencing birth weight and their relative influence during different parts of the growth period.

In such a study it becomes obvious that factors such as birth weight, early gains, weaning weight, litter size, and gestation period are closely correlated with one another. Heredity, environmental conditions such as feed, certain seasonal changes, and condition of the dam will also be recognized as influencing some or all of these factors.

Conditions affecting the dam would be expected to affect the young directly or indirectly, especially during gestation and for a short period thereafter. The question arises whether as the young approach maturity the effects on growth of the factors named above

[1] Italic numbers in parentheses refer to Literature Cited, p. 34.

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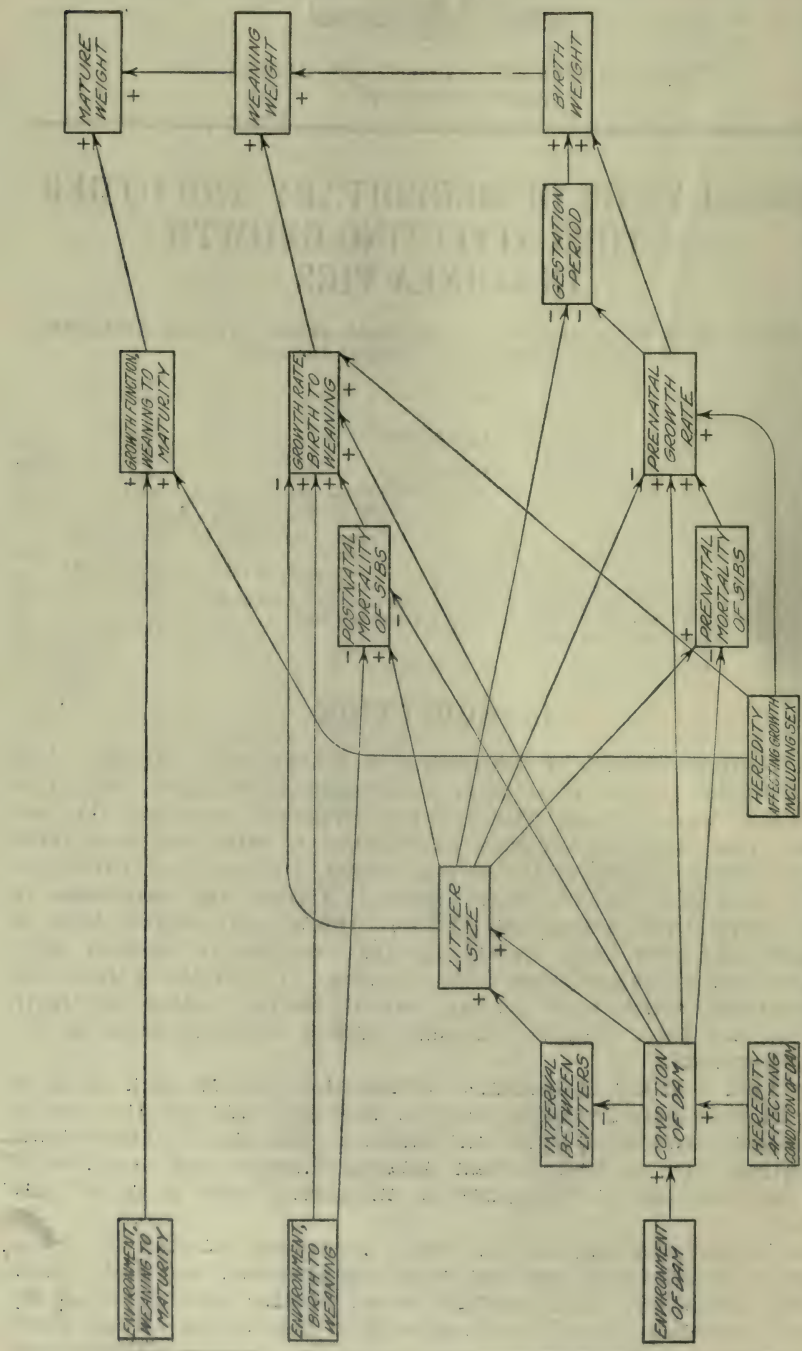

FIGURE 1.—Diagram of the paths of action of the various factors which affect the mature weight of guinea pigs

disappear or have a tendency to persist. Some of these effects, such as litter size, are due almost entirely to the dam, either to her heredity for producing large or small litters, or to some condition which affects the prenatal mortality of the young. The sire's influence on the young would be expected to be very small except for general heredity or influence on size or growth rates.

Mathematical measurement of some of the influences contributing to the growth of the young or the number of young can not be made. For example, the only satisfactory measurements which can be made of condition of dam are age and weight at time of parturition. Within a given line of heredity, females of the same age and breed should have a weight conforming within certain limits to the average weight of females for that age and breed. One which has a marked deficiency in weight would be regarded as being subnormal in general condition. Very young and very old females are not considered to be as good producers as females somewhat midway between these limits.

Effect of feed can be best expressed as a general upward or downward trend of growth and by increased or lessened mortality immediately after a change of feed.

Similarly, seasonal conditions are expressed by trends in the growth and mortality curves. These influences undoubtedly do exert an appreciable effect on some of the factors that can be more definitely measured, and affect, to a certain extent, the real value of the correlations between them.

A diagram showing possible relations between various factors affecting growth is shown in Figure 1. In this diagram the paths and direction of influence are shown by the arrows connecting the various factors represented. Whether the factor concerned exerts a positive or negative influence on another is shown by a plus or minus sign.

The data from which these studies have been made were obtained from the guinea-pig colony maintained by the Bureau of Animal Industry at its experiment farm near Beltsville, Md. Five inbred lines out of 23 lines with which the experiment was begun in 1906 have been kept to the present time by means of brother-sister mating. These are designated as families 2, 13, 32, 35, and 39, the numeral being the identification number of the ancestral female of each line. A control stock, B, with no matings more closely related than second cousins has been maintained for comparison. All have been under like conditions of management and feed; temperature and other conditions are kept as nearly uniform as it is economically possible to do so. Records are kept of the young born, including the day of birth, sex, color, birth weight, weight of sire and dam, and any other facts of interest such as deformities, peculiar spotting, or unusual size. From January, 1916, to June, 1923, weights were taken at the ages of 3, 13, 23, and 33 days, the last being the age at weaning; but since June, 1923, the keeping of weights between birth and weaning has been discontinued. The breeding animals are weighed at 53 days of age and every 30 days thereafter until death or removal from the experiment. By this system it is possible to record the age of sire and dam at the birth of each litter and the interval between succeeding litters.

Green feed throughout the year varies from freshly cut grass or alfalfa in summer to cabbage or kale in the winter. There has been considerable variation in the quality of the green feed at different times during each year. The hay fed has varied from timothy and poor clover to the highest quality alfalfa. The grain ration has consisted exclusively of whole oats.

PREVIOUS WORK

Considerable investigation has been made of the relation to one another of various factors affecting the growth of animals. Eckles (*3*) finds that in dairy cattle the age of the dam has an important bearing on the vigor of the calves produced, those between 5 and 10 years old producing the most vigorous calves. The length of gestation period and probably the weight of the dam also are correlated with the weight of the calf at birth. Weight of sire has little to do with the birth weight of the calf unless the sire is of a different breed from the dam. The nutrition of the cow during gestation appears to have little influence on the birth weight of the calf. In cattle, breed seems to be the most important factor influencing birth weight. Carmichael and Rice (*2*) find that in swine litter size increases with age of dam up to a maximum, after which there is a decrease. Investigations of Jones and Rouse (*7*) show that for multiparous animals the frequency of litters increases with the age of the dam, but this is not definitely determined for uniparous animals. King (*8*), working with rats, finds that age of dam has an influence on weight of young at birth. The young female is growing and uses energy that would otherwise go into the embryos if she were mature. The female's body weight is determined by her health, age, and other factors, all of which are reflected in the weight of the young. Large litters have a shorter gestation period, and the lactation period of the female affects the length of gestation period for the next litter. First litters are usually smaller and average lighter in weight than following litters. In a later work (*9*) the same author states that first litters usually are an index of the fertility of the female; if the first litter is large, the others are likely to be large. Litters from very young females are more variable in size and weight than those from older females. The sex of the young is not appreciably affected by age of dam.

Kopeć (*11*), working with rabbits, has carried on studies very similar to those of the Bureau of Animal Industry on guinea pigs and has obtained similar results. In another paper (*12*) he reports effect of litter size, nutrition and age of dam, and length of gestation period on weight at birth and effect of various of these factors on litter size. He finds a correlation of -0.71 ± 0.06 between litter size and birth weight except in an F_2 reciprocal cross where the correlation is -0.52 ± 0.07. Age of dam affects litter size only in the case of old females which produce larger litters and heavier young than very young females. Length of gestation period and litter size have a correlation of -0.59 ± 0.07, and weight of young is directly correlated with length of gestation period. In another paper Kopeć (*13*) states that there is a correlation between the birth weight and all following weights, but that if the animals are grouped according to litter size this correlation disappears.

EXPERIMENTAL DATA

FACTORS AFFECTING LITTER SIZE

CONDITION OF DAM

It has been stated previously that the most satisfactory data available on the dam's condition are her age and weight at time of parturition. These factors were used in this study in measuring the effect of the dam's condition on the various characteristics of the young. In most of the matings made, the male and female are put together at weaning time (33 days of age). A vigorous female is sexually mature at this time, but it is usually a month later before the male reaches sexual maturity. Since the gestation period averages about 67 days, a female's first litter is usually born when the female is between 4 and 5 months old. Her reproductive period extends to about 30 months of age, but litters are frequently produced by females much older.

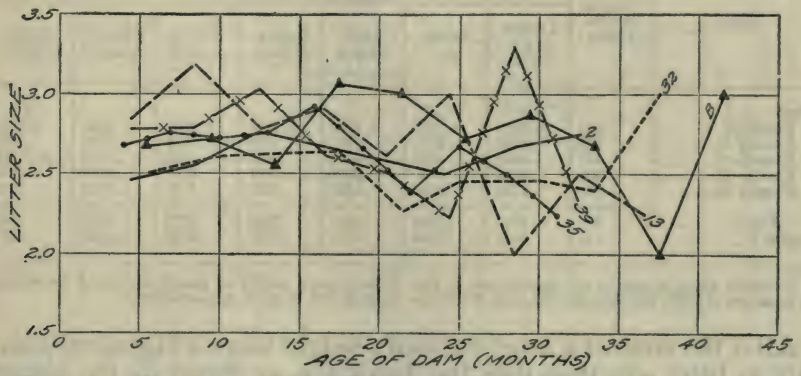

FIGURE 2.—Effect of age of dam on litter size in the five inbred families and control stock of guinea pigs

King (*9*), Kopeć (*12*), and Hammond (*5*) find that the litter size in rats, rabbits, and swine increases to a maximum as the dam's age increases to a certain age, varying for each species, after which the litter size decreases.

There is a slight indication of this for guinea pigs also, but in general there is a great variation for all ages, as shown in Figure 2. The maximum litter size appears in general to occur in inbred stock when the dams are between 12 and 16 months old and in the control stock when the dams are about 18 months old. The reason for the difference between inbred and control stock can not be that the inbreds are mated when slightly younger than the control stock and have produced more litters, for the maximum litter size occurs at about two litter ranks higher in control stock B than in the inbred lines. The reason may be that the inbreds reach their maximum reproductive capacity at an earlier age because of earlier maturity, and that the control stock, maturing later and being more vigorous, retains its high reproductive powers to a greater age.

The relationship between dam's age and litter size is not linear; therefore, the correlation ratio, expressed by the symbol η, is used.

This is computed by the formula $\eta xy = \frac{\sigma xy}{\sigma x}$, in which x and y are the two variables, σxy is the standard deviation of the means of the x arrays, and σx is the standard deviation of the x's. No correction factors have been used in any of the correlation ratios in this bulletin. The values for families 2, 32, and 35 are similar, 0.14, 0.15, and 0.16, respectively, whereas for families 13 and 39 the respective values are 0.25 and 0.27. (Table 1.) The differences, however, are not statistically significant, nor does control stock B, with a value of 0.31, differ significantly from the inbred lines taken separately or from their average value of 0.19, averaged by weighting each family by the number of individuals concerned. This seems to indicate that litter size is more uniform in the inbred lines than in the control stock and, therefore, less influenced by the dam's age.

TABLE 1.—*Correlation ratio of age of dam on various factors in guinea pigs*

Stock	Number of individuals [1]	Correlation ratio of age of dam to—						
		Length of gestation	Litter size	Birth weight	Gain to 33 days	33-day weight	53-day weight	353-day weight
Inbred:								
Family 2	232	0.3089	0.1439	0.1278	0.2298	0.1957	0.2337	0.1693
Family 13	215	.1740	.2494	.1467	.2304	.1973	.2159	.1531
Family 32	187	.1250	.1503	.2181	.2068	.1745	.2133	.1503
Family 35	184	.2838	.1591	.2018	.2791	.2773	.2598	.2315
Family 39	128	.1746	.2747	.2537	.4457	.4164	.3185	.2115
Total	946	.2319	.1898	.1814	.2642	.2376	.2422	.1797
Control B	113	.2545	.3138	.2519	.2893	.2949	.2565	.3974

[1] Numbers given apply to all correlations in this table, except length of gestation period for which the numbers are 673, 459, 293, 251, 121, and 488 for the inbreds and B stock, respectively.

After the birth of a litter the dam's weight bears a higher relationship to litter size than does the dam's age, as shown by the higher correlation ratio values. The real influence is probably not the dam's weight but her general condition of health or vigor, which is expressed in her weight. There is less variation in the correlation values of the different families and control stock than there is in the correlation between age of dam and litter size. The average value of η for the five inbred families is 0.26 and for control stock B 0.34. (Table 2.)

TABLE 2.—*Correlation ratio of weight of dam on various factors in guinea pigs*

Stock	Number of individuals	Correlation ratio of weight of dam to—					
		Litter size	Birth weight	Gains to 33 days	33-day weight	53-day weight	353-day weight
Inbred:							
Family 2	232	0.2057	0.1910	0.1674	0.2021	0.1922	0.2005
Family 13	215	.2799	.3922	.2856	.3331	.3497	.2245
Family 32	187	.2141	.3032	.4088	.3996	.3820	.2184
Family 35	184	.2554	.4628	.2959	.3779	.3805	.3330
Family 39	128	.3798	.4820	.4088	.5077	.4523	.4043
Total	946	.2574	.3511	.3032	.3464	.3391	.2628
Control B	113	.3363	.4417	.3092	.3736	.3183	.3539

LITTER RANK

Litter rank and age of dam are necessarily closely correlated, as litters should be produced at about 69-day intervals after the first litter, provided the sire and dam mate regularly. In some cases one or more oestrus periods of about 16 days are skipped before mating again occurs. In a few other cases old males have been mated to young females or vice versa. These cases are so few, however, that the coefficient of correlation between litter rank and age of dam is 0.91 for the inbred lines and 0.95 for the control stock B.

Various investigators find that litter rank affects litter size. King (*9*) states that with rats, first litters are the smallest and are also usually an index of the dam's fertility. There is a general tendency for litter size to increase from first litters to the third or fourth and

FIGURE 3.—Effect of litter rank on litter size in the average of five inbred families and the control stock of guinea pigs

then gradually to decrease. This is shown in Figure 3. The curve is erratic after the eighth litter in the inbreds and the tenth litter in the control stock because of the few litters involved. The largest litters in control stock B occur at a later birth rank than in the inbreds, a fact which may be due to earlier maturity of the inbreds or to more frequent mating of the controls. The average value of the correlation ratio of litter rank to litter size is 0.18 for the inbred lines and 0.32 for the control stock. (Table 3.) In the individual inbred families the correlation ranges from 0.14 in family 35 to 0.21 in family 32. The high value of the B stock is rather outstanding, but in no case is the difference between this stock and the inbreds statistically significant.

Relation between size of first and later litters was calculated for family 2, which was typical of the inbred families and had a large number of litters, by weighting the number of first litters by the number of later litters produced in a particular mating. This gave 1,110 litters entering into the correlation with an average size of 2.61 for first litters and 2.92 for later litters and 0.10 as the coefficient of correlation between them. This is not a high correlation and could

hardly be interpreted as indicative of the size of later litters. It disagrees with the statement of King (*9*) that first litters are an index of the dam's fertility, if fertility is considered in terms of litter size.

TABLE 3.—*Correlation ratio of litter rank to various other factors in inbred and control stocks of guinea pigs*

Stock	Number of individuals	Correlation ratio of litter rank to—		
		Litter size	Birth weight	Gain from birth to weaning
Inbred:				
Family 2	232	0.1768	0.2099	0.2007
Family 13	215	.1700	.1528	.2631
Family 32	187	.2116	.2067	.1802
Family 35	184	.1448	.1829	.2033
Family 39	128	.1928	.2937	.3057
Total	946	.1794	.2024	.2255
Control B	113	.3173	.2531	.2224

SEASON OF YEAR

Wright (*18*) shows that season of the year in which guinea pigs are born has an influence on litter size. King (*10*) finds this true also with rats and cites many instances from the works of other investigators who have found a seasonal effect on the breeding of various animals. In general, it may be said of guinea pigs that the largest litters are born late in the summer and the smallest in the winter. When litter size in each month is considered separately, there is so much variation that no conclusion can be drawn. The variation among the different families suggests that they respond differently to the same seasonal condition. This is further borne out by the higher death rates in families 32, 35, and 39 during adverse conditions, a matter which is discussed later. Families 2 and 13 seem the easiest to keep alive and propagate. King (*10*) states that this seasonal effect is an indirect one, acting through the dam. Scarcity of good succulent feed and suddent temperature changes in winter reduce the vitality of the dam, but normal conditions in the spring and summer restore vitality.

The primary seasonal influence on litter size occurs at conception, about 67 days before the birth of the litters. Therefore, it is the seasonal condition at that time and not at birth that affects litter size. Litters born late in the summer, then, are conceived early in the summer or in midsummer, when conditions are favorable, and those born in winter and early in the spring are conceived late in the fall or in the winter, when conditions are not so favorable.

HEREDITY

It has been shown by many investigators with livestock and laboratory animals that breeds differ in conformation, weight, fertility, and other factors. In the guinea pigs from which the data for this bulletin were obtained, Wright (*16*, *17*), Wright and Eaton

(*19*), and McPhee and Eaton (*14*) have shown that there are distinct differences in litter size, birth weight, and other characters among the inbred and control stocks. These different lines have as distinctly different characteristics as the breeds of livestock which differ in similar characters. If the sire and dam are of the same breed, they are expected to reproduce breed characteristics in their offspring. Variation in litter size may be considered as characteristic for the different inbred lines, but just how much this has been fixed by heredity may be ascertained from a study of the variability of litter size between the inbred and control stocks.

The coefficient of variability of litter size for the inbred lines is 31.56 and for control stock B is 33.98. The inbreds, therefore, are 87.72 per cent as variable as is the control stock. By squaring this percentage the variance of the inbreds is obtained, which is 76.94 per cent. Subtracting this from 100 per cent, considered as the total variance of a random-bred stock, gives 23.06 per cent as the variance due to genetic factors which has been reduced by inbreeding. This is less than one-fourth the assumed total variability of the stock at the beginning of the experimental breeding. Therefore, heredity does not play so large a part in determining litter size as might at first be expected. King (*10*) states that among various factors studied in rats, litter size is by far the most constant, a statement which agrees with the data here presented.

FACTORS AFFECTING BIRTH WEIGHT

LITTER SIZE

Litter size is probably the most important factor in determining birth weight of guinea pigs. There is a gradual drop in weight from individuals born in litters of one to those born in larger-sized litters. In previous data Wright (*17*) has reported the coefficient of correlation between litter size and mean birth weight of litter to be -0.66. The data presented in this bulletin do not include all young, as did Wright's data, but only males which were mated between 1916 and 1925. The coefficient of correlation is only slightly lower, however, than Wright's, having a value of -0.62 for the average of all inbred lines and -0.60 for the control stock. (Table 4.) The difference among the various inbred families shows a range from -0.52 in family 35 to -0.71 in family 32. The difference between these values is -0.19 ± 0.065, which is considered significant. This difference is probably due to the fact that birth weight was less variable in family 32, as shown by the coefficient of variability, than in any of the other stock. Litter size in this family was as variable as the average variability for all inbred lines. On the other hand, birth weight was more variable in family 35 than in family 32, whereas litter size was less variable than the average for all inbreds. By decreasing one variable and increasing the other the coefficient of correlation becomes lower.

TABLE 4.—*Correlation between litter size and weights at ages indicated in inbred and control stocks of guinea pigs*

Stock	Number of individuals	0 days	33 days	53 days	83 days	173 days	263 days	353 days
Inbreds:								
Family 2	232	−0.6313	−0.4254	−0.3063	−0.2072	−0.2436	−0.2413	−0.2055
Family 13	215	−.6470	−.4368	−.3170	−.2182	−.1825	−.1233	−.1220
Family 32	187	−.7064	−.4803	−.3669	−.2335	−.2096	−.2042	−.1818
Family 35	184	−.5230	−.3699	−.2138	−.0803	−.0289	+.0527	+.0416
Family 39	128	−.5828	−.3225	−.1817	−.0600	−.0729	−.0394	−.0925
Total	946	−.6221	−.4195	−.2859	−.1703	−.1581	−.1226	−.1185
Control B	113	−.6038	−.3292	−.2366	−.1758	−.1506	−.1148	−.1185

Stock	Number of individuals	443 days	533 days	Number of individuals	623 days	713 days
Inbreds:						
Family 2	162	−0.1883	−0.2018	112	−0.1721	−0.0748
Family 13	145	−.1580	−.2545	102	−.1256	−.0978
Family 32	135	−.3071	−.3095	98	−.3189	−.1832
Family 35	104	+.0378	+.0003	61	−.2096	−.1401
Family 39	95	+.1174	+.0855	67	+.0136	−.0096
Total	641	−.1245	−.1601	440	−.1712	−.1034
Control B	85	−.1118	−.1270	68	−.0550	−.0327

LENGTH OF GESTATION PERIOD

It has often been noticed in the guinea-pig records that young carried longer than the normal gestation period are heavier than those born earlier. This is true of all mammals. The gestation period of the guinea pig varies from 62 to 76 days, with the average about 68 days. No young born in less than 62 days after the preceding litter were alive at birth or survived more than a few hours, and those born later than 76 days afterwards should probably be considered as having been conceived at the second period of oestrum after the previous litter.

The coefficient of correlation between length of gestation period and birth weight averages 0.40 for the inbred lines and 0.44 for the B stock. (Table 5.) Family 13 has the lowest coefficient among the inbreds, with a value of 0.28, which does not, however, differ significantly from the average for all inbred lines. This difference in correlation is due to greater variability in length of gestation period and average variation in birth weight, as explained previously.

TABLE 5.—*Coefficient of correlation of length of gestation period to birth weight in inbred and control stocks of guinea pigs*

Stock	Number of individuals	Correlation	Stock	Number of individuals	Correlation
Inbred:			Inbred—Continued.		
Family 2	1,110	0.4601	Family 39	161	0.3426
Family 13	689	.2805			
Family 32	403	.4202	Total	2,720	.4040
Family 35	357	.4770	Control B	912	.4364

Minot (*15*) states that large litters average less in weight than do small litters, since they are in the uterus a shorter period and as a result have a shorter time in which to develop. Ibsen (*6*) disagrees with this statement, as the young which he compared in different sizes of litters were in the uterus the same length of time. He believes that difference in weight at birth is due to difference in number in the litter rather than to length of prenatal-growth period. The data in this bulletin seem to indicate that both these conditions are influential factors of birth weight, for small litters have a longer gestation period than large litters (Table 6) and when the number of fetuses is small there is more nourishment available for each from the uterine circulation than when the number of fetuses is large.

TABLE 6.—*Length of gestation period in different-sized litters in inbred and control stocks of guinea pigs*

[Average size of litter for each family is given in parentheses]

Litter size	Family 2 (2.38)		Family 13 (2.66)		Family 32 (2.15)		Family 35 (2.31)		Family 39 (2.71)		B stock (2.76)	
	Litters	Average gestation period	Litters	Average gestation period	Litters	Average gestation period	Litters	Average gestation period	Litters	Average gestation period	Litters	Average gestation period
	Number	*Days*	*Number*	*Days*	*Number*	*Days*	*Number*	*Days*	*Number*	*Days*	*Number*	*Days*
1	108	69.83	78	71.44	67	72.23	63	71.06	14	68.93	80	71.08
2	287	68.88	131	70.31	74	70.84	85	70.39	39	69.76	131	70.58
3	189	68.25	129	69.81	66	70.09	70	69.53	42	68.74	129	69.34
4	80	67.78	81	68.61	13	69.12	29	68.47	16	67.44	102	68.53
5	6	66.67	27	68.13	3	67.50	4	70.00	8	67.38	38	68.08
Total or average	670	68.70	446	69.86	223	70.89	251	70.32	119	68.70	480	69.65

EFFECT OF LITTER SIZE ON LENGTH OF GESTATION PERIOD

The average length of gestation period in families 2 and 39 is 68.7 days; in families 13 and the B stock, 69.8 and 69.6 days, respectively; and in families 32 and 35, 70.9 and 70.3 days, respectively. (Table 6.) This grouping does not correspond with average litter size for these families; length of gestation is, therefore, dependent on some factors aside from this.

Average length of gestation period for litters of one in all the inbred lines is 70.9 days, whereas for litters of five the average is 67.9 days. The coefficient of correlation between gestation period and litter size averages -0.37 for the inbred lines and -0.43 for the control stock.

The reason for gestation period varying for different sized litters has not been satisfactorily explained. It can not be a matter of weight of the fetuses, for there are numerous cases in which a litter of 1 or 2, although it exceeded in weight that of a litter of 4 or 5, was carried 73 to 75 days whereas the litter of 4 or 5 was expelled at about 65 days. Hammond (*5*) lists several theories of the causes of birth taken from Williams's Veterinary Obstetrics. Among those seeming most likely, from the observations on guinea pigs, are in-

creasing size of the fetus and consequent increasing distension and irritability of the uterus, and the possibility of the action of hormones.

EFFECT OF AGE OF DAM ON LENGTH OF GESTATION PERIOD

Age of dam seems to have an effect on the length of the gestation period of guinea pigs (fig. 4), the younger females having the shorter period. This is true for all the inbred lines, but there is considerable variation among them. Families 2, 35, and 39 have a very perceptible rise in length of gestation period for increase in age of the dam, bearing almost a linear relationship. The drop or rise at or near the end of the graphs is due to but one litter at these ages of the female. The gestation periods of families 13 and 32 seem to be less affected by dam's age. The difference in length of gestation period in the first 3 families named varies more than a day for females at 4 months of age and those at 30 months of age; for the last 2 families the

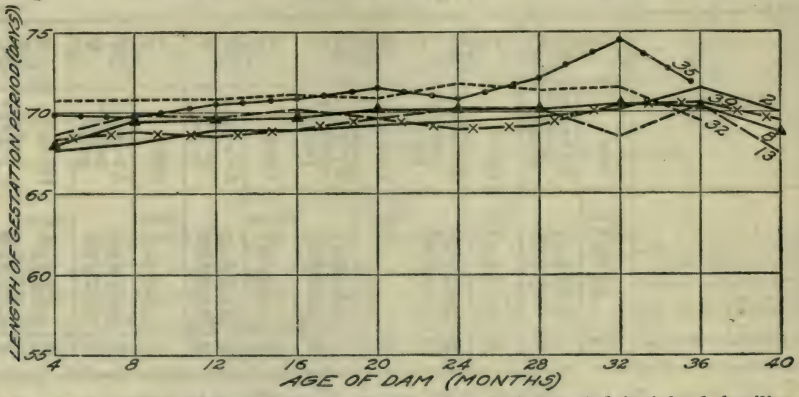

FIGURE 4.—Effect of age of dam on length of gestation period in inbred families and the control stock of guinea pigs

difference is only about half a day for the same age differences. Stock B has a gradual rise in length of gestation period from females 4 months old to 32 months old and then a decline, but the length of gestation period is nearly a day greater for females 40 months old than for those 4 months old and the maximum gestation period at 32 months of age is slightly more than 1½ days longer than at 4 months. The value of η for the five inbred lines is 0.23 and for B 0.25. (Table 1.)

These results appear to contradict the fact that litter size also rises with age of dam; consequently, length of gestation period should drop. The rise in litter size, however, is not so great as the difference in days of gestation, and after the maximum litter size is reached at about the twelfth to sixteenth month of the dam's age, litter size decreases. A possible explanation of the increase in gestation period in older females, which are producing on an average slightly larger litters, is found in the theory of parturition because of irritation and distension of the uterus. Since the birth weight and consequently the number of pigs in first litters are only very slightly smaller than in later litters, and since the uterus of the young female and the female herself as an organism have not reached their maximum physical

development, less distension and irritation of the uterus are necessary to cause parturition in a young female than in an older one which has reached maximum physical development, and therefore a young female will expel the fetuses earlier.

CONDITION OF DAM

Since the condition of the dam, as expressed by age and weight, has been found to influence litter size to a certain extent, it is to be expected that weight at birth will be influenced also by these factors. King (*9*) working with rats, Kopeć (*11*) with rabbits, Eckles (*3*) with cattle, and Carmichael and Rice (*2*) with swine, have found this relationship between age of dam and birth weight of

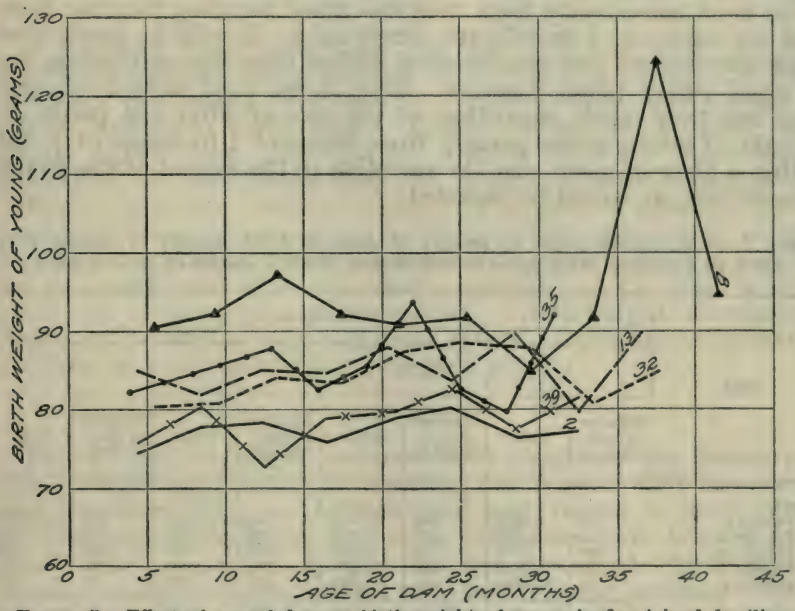

FIGURE 5.—Effect of age of dam on birth weight of young in five inbred families and the control stock of guinea pigs

young to exist. In all cases the young from mature dams were heavier than those from young females. In guinea pigs this is also true to a slight degree, as shown by Figure 5. Not much weight is to be placed on results after 30 months, as only a few females bore young after this age. The value of the correlation ratio of age of dam to birth weight of young was 0.13 and 0.15 for families 2 and 13, respectively, and 0.22, 0.20, 0.25, and 0.25 for families 32, 35, 39, and B. The differences in these values are in no case statistically significant. The average value for all the inbred lines is 0.18. (Table 1.)

Since weight of dam is more of an indication of the dam's health and vigor than is age, a closer relationship to the birth weight of the young would be expected. This is shown in higher correlations between these factors. All inbred families except family 2 have a correlation ratio of more than 0.3. (Table 2.) The low value of 0.19 for family 2 appears to be due to greater variability of the birth

weight of the young in the data from which these figures are calculated than in the other inbred lines. The average correlation ratio of weight of dam to birth weight of young is 0.35 for the inbred lines and 0.44 for the control stock. The difference is not statistically significant.

When the young are classified as to size of litter in which they were born, the correlation between the dam's weight and the birth weight of the young increases as the litter size increases. The averages for the 5 inbred families are 0.56, 0.57, 0.58, and 0.61 for litters of 1 to 4, respectively. (Table 7.) Family 13 has the lowest correlations, which range from 0.45 for litters of 1 to 0.58 for litters of 4. There is considerable variation among the families as to the highest correlation in different litter sizes, but family 39 appears to be more consistently high than the other families, ranging from 0.56 for litters of 1 to 0.74 for litters of 4. It will be noted that these correlations are considerably higher than the correlation for all-sized litters taken together. This shows that weight of dam does not vary much, regardless of the size of litter she produces. Weight of young varies greatly from litters of 1 to litters of 4, but within a litter of given size, the variation in the weight of the young is much less, as would be expected.

TABLE 7.—*Correlation ratio of weight of dam to birth weight of young born alive in different litter sizes in inbred and control stocks of guinea pigs*

Stock	Litter size of—							
	1		2		3		4	
	Number of individuals	Ratio	Number of individuals	Ratio	Number of individuals	Ratio	Number of individuals	Ratio
Inbred:								
Family 2	147	0.6815	802	0.5460	918	0.5592	268	0.5837
Family 13	149	.4467	586	.5471	723	.5139	320	.5709
Family 32	184	.5578	588	.5640	477	.5971	104	.6748
Family 35	121	.5352	508	.6354	609	.6119	168	.6151
Family 39	55	.5598	206	.5897	264	.6796	96	.7430
Total	656	.5563	2,690	.5704	2,991	.5757	956	.6128
Control B	122	.4402	504	.5876	786	.5946	436	.5967

In the B stock the correlation does not differ greatly from that in the inbred lines, being 0.45, 0.59, 0.59, and 0.60 for litters of one to four, respectively. This is more variable, however, than the correlations in the inbred stock and is due probably to greater variability among the weights of different litter sizes.

LITTER RANK

The effect of litter rank on birth weight is small, as shown by a correlation ratio of only 0.20 for the average of all inbred lines and 0.25 for the control stock. (Table 3.) There was a marked variation from these values in family 39, in which the value of η was 0.29, but the difference between this family and the other inbreds is not statistically significant and may be due to the fact that fewer numbers enter into this calculation than enter into the others except in control stock B.

The average birth weight for first and later litters of family 2 was computed in the same way as explained for litter size in first and later litters. First litters averaged 70.5 grams in weight and later litters 71.1 grams, with a coefficient of correlation between them of 0.06. It must be remembered, however, that the average size of litters after the first was 0.31 larger than the first litter. This should result in a smaller birth weight of young in litters after the first than in the first litter; therefore, the real difference in average weight between young born in first litters and later litters is considerably more than 0.6 gram when corrected to constant litter size. However, this does not give a significant correlation between the birth weight in first and later litters.

SEX

It has long been recognized that the weight at birth and maturity and growth rates of animals of the two sexes differ. In most mammals the male is the heavier. Male guinea pigs average 3 grams heavier at birth and 8 grams heavier at weaning than female guinea pigs, according to a study made by Haines (*4*). According to unpublished data the present author finds that the difference in weight between males and females at maturity varies from 70 to 120 grams according to the families to which they belong. Therefore, in studying weight relations in guinea pigs it is important to consider the sexes separately, especially in the later weights where the differences become greater. Birth-weight correlations would not be affected to such a great extent. Correlations involving the litter as a unit necessarily disregard sex.

HEREDITY

Part of the correlation between birth weight of the young and dam's weight may be due to heredity, for Wright (*17*) has shown that the inbred lines are differentiated with regard to their weight at birth and weaning and that these differences have become practically fixed characters for the families concerned. McPhee and Eaton (*14*) have shown that not only the birth and weaning weights but also the mature weights of the different inbred lines have become fixed. This being the case and birth weight in guinea pigs being about one-tenth of mature weight, a relation must exist between dam's weight and birth weight of the young.

Computed by means of variability coefficients, the average of all the inbred lines is 53 per cent of the variance of birth weight of the control stock, leaving 47 per cent of the variability of the inbreds genetic and bred out by close inbreeding. This being the case, heredity is a larger factor in determining birth weight, where nearly 50 per cent of variability has been bred out, than in determining litter size, where less than 25 per cent of variability has been bred out.

CHANGES IN TEMPERATURE AND FEED

Guinea pigs are very sensitive to sudden changes of temperature and feed. In the guinea-pig colony from which these data are derived, an effort is made to keep conditions as nearly uniform as possible, but there is of necessity wide variations in temperature and in feed from season to season. In the summer, temperature runs

to above 90° F. at times. In the winter an attempt is made to maintain a temperature of 70°, but in severe weather it frequently drops to 50°. Sudden changes of temperature are usually followed by colds, pneumonia, and death, both of young and old. Through the winter cabbage or kale is fed, and early in the spring before fresh green feed can be cut it often becomes very inferior in quality. The green feed late in the spring, through the summer, and early in the autumn includes lawn clippings, good alfalfa, Sudan grass, soybeans, and rye. The last three feeds do not seem to be satisfactory for guinea pigs. The kind of hay varies from timothy and poor clover to the highest quality alfalfa. These variations are reflected in low gains and high mortality. The grain fed consists exclusively of unground oats.

Unlike the seasonal effect on litter size occurring primarily a little more than two months before the birth of a litter, seasonal effect on birth weight continues over the whole period from conception to birth. The influence is wholly through the dam and affects the young less than might be expected because nourishment of the fetus is entirely from the blood stream of the dam and, as Eckles (*3*) states, there is a strong tendency for the composition of the blood to remain constant, even under adverse conditions of nutrition. In case of food shortage during gestation, the dam, not the fetus, suffers. In inbred families 2, 32, and 39 the heaviest pigs were born during the 3-month period, October to December. In family 13 the heaviest pigs were born during April to June and in family 35, during January to March. In the inbred lines as a whole the heaviest young were born during October to December. Among the control stock the heaviest were born during January to March. When the birth weights by individual months are considered, there is so great variation that no conclusion can be drawn. The lightest young were born in general during July to September. This is the period during which the largest litters occurred; therefore, the relationship here may be due to litter size rather than to season, for litter size is an important factor in the determination of birth weight, as was shown previously.

MORTALITY

Mortality, both prenatal and postnatal, has an indirect relation to growth. Prenatal mortality is expressed as percentage of young born alive, the difference between 100 per cent and this percentage being the percentage dying before birth. This may not represent the actual prenatal death rate, however, for some of the young reported dead at birth may actually have been alive when born but may have died before they were found, as 14 hours sometimes elapse between actual birth and the time the young are found by the caretaker. Haines [2] found by comparing the number of corpora lutea with the number of fetuses in females killed shortly before parturition that there was an excess of corpora lutea, a fact which showed that some of the fetuses develop for a short period, then die, and become resorbed. Several fetuses were found in process of resorbtion

[2] HAINES, G. H. A STATISTICAL STUDY OF THE RELATION BETWEEN VARIOUS EXPRESSIONS OF FERTILITY AND VIGOR IN THE GUINEA PIG. 1929. (Unpublished part of thesis, Ph. D. Univ. Md.)

during this investigation. Thus the true percentage of prenatal mortality may be greater or less than actually reported as young born alive. Data presented in Table 8 and Figure 6 show that litters of 4 and 5 and litters of 1 have greater prenatal mortality than litters of 2 and 3. Haines (*4*) found also that the young raised to weaning average about 14 grams heavier at birth than those born dead. This difference may be due to more available nutrition from the blood stream of the dam after the death of the sibs took place. The number of young dead at birth may also give a clue to the dam's general condition.

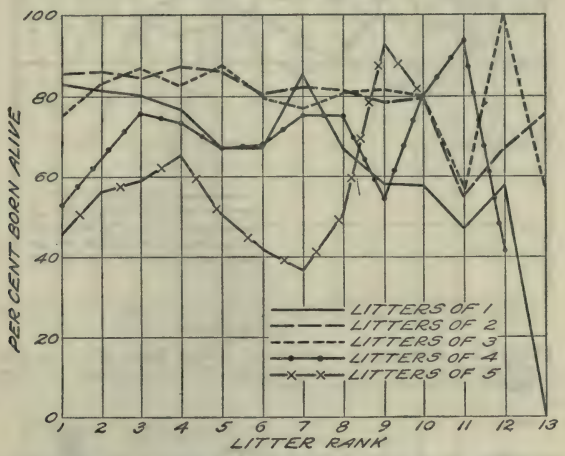

FIGURE 6.—Percentage of young born alive in the different litter sizes and ranks for the average of five inbred lines of guinea pigs

TABLE 8.—*Percentage of young born alive and percentage raised of those born alive in different litter sizes and ranks (average of inbred lines)*

PERCENTAGE BORN ALIVE

Litter size	Litter rank of—												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	82.89	81.25	80.37	76.77	67.37	67.12	85.00	66.67	58.06	57.89	46.67	57.14	0
2	85.55	86.06	84.35	87.23	86.13	80.31	82.48	81.44	78.57	79.27	54.54	66.67	75.00
3	74.85	82.77	86.53	82.51	87.37	80.00	77.38	80.25	81.63	79.36	56.67	100.00	58.33
4	52.43	64.01	75.95	73.73	67.10	67.67	75.00	75.00	54.54	80.00	93.75	41.67	------
5	45.71	56.00	58.95	65.00	50.00	42.00	36.67	50.00	93.33	80.00	------	------	------
Total	75.20	77.02	80.34	80.83	78.95	74.01	77.30	78.26	75.66	77.51	60.00	69.56	61.90

PERCENTAGE RAISED OF THOSE BORN ALIVE

1	74.60	75.21	80.23	75.00	82.81	75.51	76.47	89.28	83.33	81.82	71.43	50.00	------
2	73.82	79.48	81.69	81.93	80.52	83.33	82.38	84.81	77.92	80.00	66.67	100.00	83.33
3	77.50	78.68	81.91	85.00	75.12	80.30	78.46	80.00	77.50	68.00	52.94	46.67	85.71
4	62.25	69.53	69.28	72.10	60.78	64.97	73.33	69.23	66.67	71.88	40.00	40.00	------
5	68.75	61.43	50.00	57.69	60.00	57.14	63.64	80.00	35.71	75.00	------	------	------
Total	74.23	76.30	77.24	78.70	73.97	76.69	78.44	81.67	75.19	74.69	57.14	59.38	84.62

Postnatal mortality is expressed as percentage raised of those born alive. The influence of this factor on growth is brought about probably during the nursing period of the young, which is probably not more than two weeks in a guinea pig, and the young even before this time are able to eat and thus are not entirely dependent on the dam for food. In large litters, the young derive less nourishment

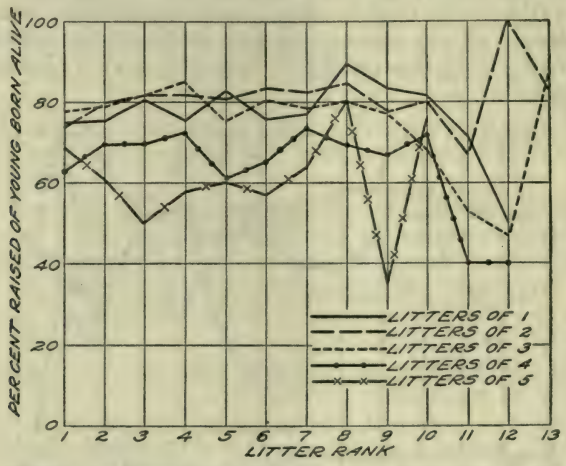

FIGURE 7.—Percentage raised of young born alive in the different litter sizes and ranks for the average of five inbred lines of guinea pigs

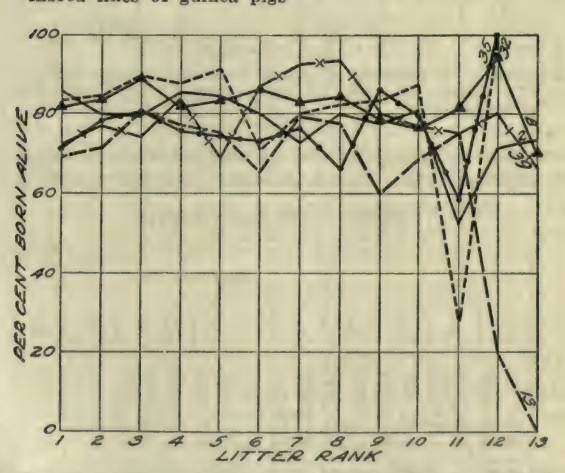

FIGURE 8.—Percentage of young born alive in all-sized and successive litters of the five inbred lines and control stock of guinea pigs

from the dam during the nursing period than the young in small litters. This may slow up the early growth rate and result in a lower weaning weight than if some of the young died during the first two weeks and made more nourishment available for the surviving young. The postnatal mortality is lowest in litters of two and three. (Table 8 and fig. 7.) The different inbred families and control stock vary in the percentages of young born alive and in the percentage raised of those born alive. (Table 9 and figs. 8 and 9.)

The ranking of the families in prenatal mortality is practically the same as their rank in weight at birth, indicating possibly a rather close relationship, but the ranking in postnatal mortality and weaning weight shows practically no agreement, indicating little or no relation.

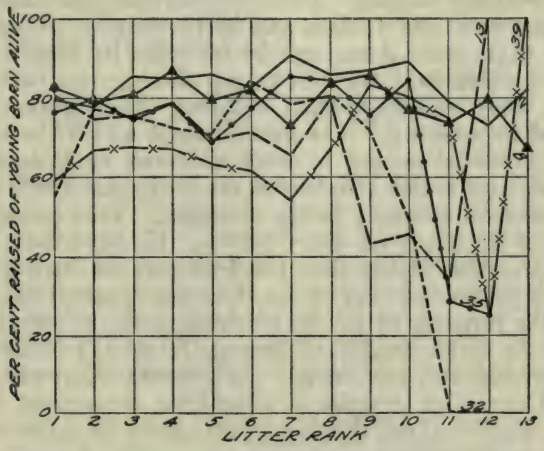

FIGURE 9.—Percentage raised of young born alive in absized and successive litters of the five inbred lines and control stock of guinea pigs

TABLE 9.—*Percentage of young born alive and percentages raised of young born alive in different stocks and ranks (average of all litter sizes)*

PERCENTAGE BORN ALIVE

Stock	Litter rank of—												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Inbred:													
Family 2	85.50	79.92	79.02	85.12	84.26	80.00	72.61	79.88	77.85	80.44	52.17	70.97	73.33
Family 13	68.97	71.00	79.72	77.14	75.64	65.17	79.36	77.50	59.74	68.63	75.00	20.00	0
Family 32	83.03	84.29	89.47	87.83	90.91	70.87	79.80	82.26	83.33	87.50	28.57	100.00	------
Family 35	71.14	78.45	80.48	75.69	74.13	73.33	76.38	66.23	86.05	79.17	58.33	100.00	------
Family 39	72.06	76.92	74.12	83.33	68.27	86.67	92.50	93.75	80.00	76.92	75.00	80.00	66.67
Total	75.20	77.02	80.34	80.83	78.95	74.01	77.30	78.26	75.66	77.51	60.00	69.56	61.90
Control B	81.55	83.30	88.91	82.10	83.56	86.44	82.44	84.43	78.57	76.22	81.43	94.12	70.00

PERCENTAGE RAISED OF YOUNG BORN ALIVE

Inbred:													
Family 2	79.80	77.95	85.59	84.81	85.81	82.33	90.86	85.93	87.07	89.19	79.17	72.73	81.82
Family 13	80.68	74.82	75.56	78.63	69.29	71.26	65.33	79.57	43.48	45.71	33.33	100.00	------
Family 32	55.25	77.02	75.94	72.29	70.77	84.44	78.48	80.39	71.43	50.00	0	0	------
Family 35	76.23	79.93	74.85	78.86	68.75	77.68	85.57	84.31	75.68	84.21	28.57	25.00	------
Family 39	59.18	66.67	67.46	66.67	63.38	61.54	54.05	66.67	83.33	80.00	75.00	25.00	100.00
Total	74.23	76.30	77.24	78.70	73.97	76.69	78.44	81.67	75.19	74.69	57.14	59.38	84.62
Control B	82.12	79.12	80.26	86.29	79.34	81.96	72.68	83.24	85.61	76.40	73.68	79.17	66.67

WEIGHTS AND GAINS BEFORE WEANING

Since the age and weight of the dam had so little effect on birth weight, it is necessary to mention only the correlation between these factors and weight at weaning (33 days of age). The correlation

ratio between age of dam and weaning weight is 0.24 for the inbred lines and 0.29 for the B stock. (Table 1.) For age of dam and gain between birth and weaning the correlation ratio is 0.26 for the inbreds and 0.29 for the B stock, practically the same as the correlations for weaning weight. These correlations are somewhat higher than those between age of dam and birth weight. This may be due to the fact that older dams are better able to furnish the proper amount of nourishment for the young during the early period between birth and weaning, thus assuring good gains through the entire period to weaning. The nourishment which the young receive during the prenatal period is more uniform, as it comes from the blood stream, and is not affected so much by the dam's vigor, as the blood composition remains fairly constant. This point is noted by Eckles (*3*) in his study of dairy calves. He says that if conditions are adverse the dam rather than the fetus suffers during the prenatal period, but a poor condition of the dam after parturition retards the growth of the nursing calf. In explaining the effect of immaturity of the dam on birth weight of young, King (*8*) states that young rats are growing and use energy that would otherwise go into the fetuses, and the birth weight is, therefore, dependent on the dam's age. With guinea pigs, the condition seems to agree more closely with that found in cattle.

The correlation ratio of weight of dam to gain between birth and weaning is 0.30 for the inbreds and 0.31 for B stock. (Table 2.) The correlation ratio of weight of dam to weaning weight of the young is 0.35 for the inbred lines and 0.37 for B stock. These values are only slightly higher than the correlation of dam's age with birth weight and gain from birth to weaning. Correlations of 0.3 are considered significant and in the cases here presented are more than 4½ times their probable error.

The correlation ratio of litter rank to gain from birth to weaning is 0.22 for both inbred and control stocks. (Table 3.) This correlation was not calculated for weaning weight since it was found of so little significance for birth weight.

The effect of litter size on weights from birth to weaning is still important. In family 2 the coefficient of correlation was calculated for litter size and weight at 3, 13, 23, and 33 days and found to be −0.64, −0.56, −0.46, and −0.42, respectively. These values differ but slightly from the average of the inbreds; in fact, the average correlation at 33 days is −0.42 for the latter also. (Table 4.) In the different inbred families this correlation agrees very closely and in no cases are the differences significant. For the B stock the coefficient of correlation between litter size and weaning weight is −0.33.

The effect of litter size on gains from birth to weaning seems to be operative for only a short period, as shown by the correlation values. The average correlation between litter size and gain between birth and weaning for the five inbred families is −0.31 and for B −0.19. The gain is dependent on the food supply and on the individual's ability to assimilate it rather than on litter size. In family 2, for which several gains between birth and weaning were recorded, the correlation between litter size and the first 3 days' gain was very low, −0.03; it rose for the next 10 days' gain to −0.30; and gradually decreased for each 10 days' gain thereafter till weaning. This indicates either practically equal gains by all young, re-

gardless of how many there are in the litter, or practically no gain. The latter condition probably results, as the correlation between litter size and birth weight was but slightly higher than that between litter size and weight at 3 days of age, a fact which shows that the relationship of weights remained practically unchanged from that at birth. The records show that in some litters the weight at 3 days of age was actually less than at birth.

The coefficient of correlation between weight at birth and at 3 days of age averages 0.94 for the five inbred families and 0.96 for B stock. (Tables 10 and 11.) There is very little variation among the inbred families in this correlation, the lowest being 0.92, in family 39, and the highest 0.95, in family 2. The correlation between weight at birth and at 13 days of age averages 0.82 for the inbreds and 0.87 for the B stock. Here the variation between the families is greater than in the previous correlation, ranging from 0.77, in family 2, to 0.89, in family 35. The correlations continue to decrease as length of time from birth increases and the variation among the different families becomes greater. The correlation between weaning weight and birth weight has decreased to 0.71.

TABLE 10.—*Average correlations between weights and between gains of young at ages indicated for the inbred lines of guinea pigs*[1]

CORRELATIONS BETWEEN WEIGHTS (DAYS)

Age	3	13	23	33	53	83	173	263	353	443	533	623	713
Birth	0.94	0.82	0.77	0.71	0.60	0.49	0.44	0.41	0.35				
3		.88	.82	.76	.64	.53	.43	.40	.35				
13			.94	.87	.76	.64	.54	.48	.41				
23				.95	.85	.71	.58	.50	.43				
33					.89	.76	.60	.50	.47	0.44	0.40	0.43	0.31
53						.90	.69	.55	.50	.47	.41	.37	.38
83							.76	.60	.53	.52	.42	.40	.38

CORRELATIONS BETWEEN GAINS (DAYS)

Period of gain	3	13	23	33	53	83	173	263	353	443	533	623	713
0-3	0.48	0.46	0.41	0.36	0.37	0.33	0.21	0.19	0.18				
3-13		.89	.84	.78	.69	.59	.50	.42	.36				
13-23			.73	.72	.68	.58	.43	.36	.31				
23-33				.59	.54	.50	.39	.27	.23				

[1] Correlations given were made on 946 guinea pigs for all ages through 353 days, 641 for 443 and 533 days, and 440 for 623 and 713 days.

TABLE 11.—*Average correlation between weights and between gains of young at ages indicated for the control stock of guinea pigs*[1]

CORRELATIONS BETWEEN WEIGHTS (DAYS)

Age	3	13	23	33	53	83	173	263	353	443	533	623	713
Birth	0.96	0.87	0.79	0.72	0.70	0.54	0.50	0.48	0.47				
3		.91	.83	.78	.67	.55	.51	.49	.52				
13			.93	.89	.77	.64	.56	.53	.53				
23				.94	.83	.70	.62	.55	.56				
33					.81	.73	.65	.66	.66	0.61	0.62	0.68	0.65
53						.76	.67	.63	.62	.57	.56	.58	.57
83							.82	.69	.65	.57	.56	.49	.51

[1] Correlations were made on 73 guinea pigs through 33 days, 113 from 53 through 353 days, 85 for 443 and 533 days, and 68 for 623 and 713 days.

TABLE 11.—*Average correlation between weights and between gains of young at ages indicated for the control stock of guinea pigs*—Continued

CORRELATIONS BETWEEN GAINS (DAYS)

Period of gain	3	13	23	33	53	83	173	263	353	443	533	623	713
0–3	0.51	0.48	0.51	0.47	0.34	0.28	0.29	0.35	0.39	------	------	------	------
3–13	------	.89	.86	.81	.70	.60	.49	.42	.40	------	------	------	------
13–23	------	------	.58	.57	.59	.58	.45	.38	.40	------	------	------	------
23–33	------	------	------	.49	.44	.49	.36	.32	.35	------	------	------	------

Correlations between weights at 3 days of age and at later periods show a similar decrease. The correlation between weights at 3 days and at 13 days is somewhat higher than that between weight at birth and at 13 days, averaging 0.88 for the 5 inbred families. The correlations of the weights at 13 days and at 23 days with the weights 10 days later are higher than the correlation between the weight at 3 days and at 10 days later, as the correlation is 0.94 between weights at 13 days and 23 days and 0.95 between 23 days and 33 days.

It has been stated previously that weight at any time is dependent on the preceding gains. Therefore, there should be a certain amount of correlation between a given gain and the weights following it for a considerable period. The gain is variable at 3 days of age; in some cases there has been a loss in weight, in others a gain of several grams. This variability does not seem to depend on the birth weight of the young, but may occur in heavy as well as light animals at birth. The average coefficient of correlation for gain during the first three days and weight at three days is 0.48 (Table 10), and it gradually decreases for the later weights. In the B stock the correlations are higher, being 0.51 between gain from birth to 3 days of age and weight at 3 days of age and correspondingly higher for the other weights.

The gain between 3 and 13 days of age is more uniform than that between birth and 3 days of age and shows a higher correlation in all cases with the weights which follow than the gain between birth and 3 days shows with its following weights. The correlation of gain between 3 and 13 days with weight at 13 days is 0.89.

The gain during the next 10-day period, from 13 to 23 days of age, does not determine to such an extent the future weights of a guinea pig as the gain during the preceding 10-day period but still is very important. The correlation between gain from 13 to 23 days of age and weight at 23 days is 0.73.

The correlation of gain between 23 and 33 days of age and with weight at 33 days averages 0.59 for the inbred families and 0.49 for B stock.

In numerous data collected by Brody (*1*) on the growth of various animals, it is shown that growth progresses at a rather uniform but decreasing rate as maturity is approached. In the present data the correlation of gain during the first three days to gain during the next 10 days averages 0.32 for the inbred families and 0.34 for B stock. For the gain from 13 to 23 days the correlation decreases to 0.17 for the inbreds but remains rather high for B stock, with a value of 0.27. In the period from 23 to 33 days the correlation is 0.15 for the inbreds but has decreased to −0.02 for the B stock.

The correlation of gain between 3 and 13 days with gain between 13 and 23 days is 0.43 for the inbreds and 0.27 for B stock, and for the period 23 to 33 days it is 0.19 and 0.20 for the inbreds and B stock, respectively. The correlation of gain from 13 to 23 days with gain from 23 to 33 days is 0.29 for the inbreds and 0.14 for B stock.

WEIGHTS AND GAINS AFTER WEANING

The correlation ratios between age and weight of dam and weights of young after weaning change very little from what they were for the earlier weights. This probably indicates that what little influence these two factors do exert on weight does not change much, even throughout the lifetime of the offspring, or, in other words, the weights of offspring at no time are more variable than the weights of their dam. For the inbred lines the correlation ratio between

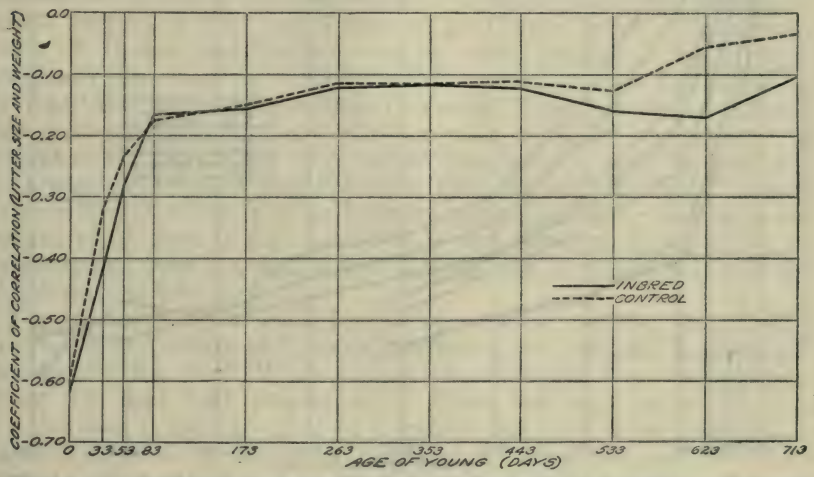

FIGURE 10.—Coefficient of correlation between litter size and weight at different periods for the average of five inbred lines and the control stock of guinea pigs

age of dam and weight of offspring at 53 days of age averages 0.24, and at 353 days, or approximately 1 year of age, 0.18. (Table 1.) The correlation values between weight of dam and weight of offspring at the same periods are 0.34 and 0.26, respectively. (Table 2.) For B stock the correlation of age of dam to weight at 53 days is 0.26 and to weight at 353 days 0.40. For B stock the correlation of weight of dam to weight of offspring at these same periods are 0.32 and 0.35, respectively. The differences between none of these values are significant.

Correlation between litter size and weight of young continues to drop after weaning. (Table 4 and fig. 10.) Among the inbreds at 83 days the coefficient of correlation is -0.17, and at 713 days, or approximately 2 years of age, it is -0.10. For B stock at 713 days the correlation is -0.03. None of these differences are statistically significant.

These correlations show that litter size has a strong influence in determining the weight of guinea pigs at birth and that this influence persists appreciably even to 53 days of age. As the young grow

there is a tendency to overcome the effects of litter size on weight, but there is some influence even to 1 year of age or beyond. This was shown by McPhee and Eaton (*14*) in growth curves of guinea pigs born in litters of different sizes.

After 33 days each succeeding weight, as shown in Figure 11 and Table 10, has about the same correlation with the weight immediately following, and these correlations decrease as the interval between weights increases. It can thus be seen that there is a correlation among all weights, and even at 2 years of age there is still a correlation of 0.31 with the weight at weaning.

One interesting observation is that between any weight selected after 53 days of age and the next 30-day weight there is a correlation of approximately 0.92. The weights selected for this determina-

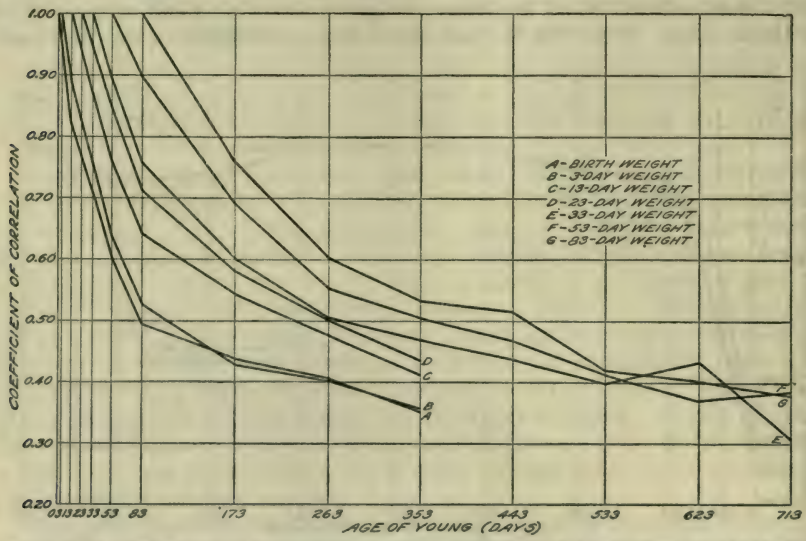

FIGURE 11.—Coefficient of correlation between weights of guinea pigs in the five inbred families at birth, 3, 13, 23, 33, 53, and 83 days of age and the following weights in each case

tion were those at 53, 147, 233, 417, and 593 days and the following weight in each case. When an interval of two 30-day periods, or 60 days, was taken, the correlation between that weight and the weight 60 days later averaged 0.84. For a 90-day interval, the correlation averaged 0.80, and for 120 days the average was 0.75. These correlations show a fairly constant relationship between any weight and its next 30-day, 60-day, 90-day, or 120-day weight, except that the correlation is lower as more time elapses between weights. Another point of interest is that the correlations are higher when taken near maturity than when taken earlier. Thus the correlation between weight at 53 days and 113 days is 0.82, between 83 days and 143 days it is 0.83, and between 443 and 503 days 0.86. This rise is general whether intervals of 2, 3, or 4 months are taken. The probable reason for this is that as maturity is approached the variability in weights and gains becomes less, and any weight near maturity bears a higher relation to the following weight, or even to its third

or fourth succeeding weight, than an earlier weight would bear to its succeeding or third or fourth following weight, where the differences in weight are greater. Also the gains are a proportionately smaller part of the following weight as maturity is reached.

RELATION OF WEIGHTS AND GAINS BEFORE WEANING TO WEIGHTS AND GAINS AFTER WEANING

For the inbreds the coefficient of correlation between the weight at 173 days, or approximately 6 months, and the birth weight is 0.44, and between weight at 353 days or approximately 1 year, and the birth weight the correlation is 0.35. For the B stock the corresponding correlations are 0.50 and 0.47, respectively. (Tables 10 and 11.) The correlation of the weight at 3 days with weight at 353 days is 0.35 for the inbred lines. This value is equal to the birth-weight correlation probably for the reason that there is so little change between weights at birth and 3 days, as previously noted. The correlations of 13-day and 23-day weights with weights after weaning gradually decrease, as in the previous cases, but are higher at 353 days as the length of time from this weight and the weight in question decreases. Thus weight at 23 days has a higher correlation with weight at 353 days than weight at 13 days has, for the length of time is shorter between 23 and 353 days than between 13 and 353 days. The coefficient of correlation between gain from birth to 3 days and weight at 53 days is 0.37. At 263 days a constant relationship apparently has been reached, for at this age the correlation is 0.19 and at 353 days is 0.18.

For the inbreds the coefficient of correlation between gain from 3 to 13 days and weight at 53 days is 0.69 and is 0.36 at 353 days weight. The values for stock B are almost identical for these correlations, being 0.70 and 0.40, respectively. From the high value of these correlations, it appears that in a guinea pig gain between 3 and 13 days of age has an important bearing on practically all its future weights. Interpreting it in another way, one can say that in order to have a vigorous animal as measured by weight, it is essential that it grow well soon after birth. In swine this period would correspond approximately to the first three weeks, and in a Jersey calf to about the first two months. The correlation between gain during the next 10-day period, from 13 to 23 days, and later weights is not so high but is still important. At 53 days the correlation is 0.68 and at 353 days 0.31 in the inbred lines and 0.59 and 0.40, respectively in the control stock. At 353 days the correlation with gain between 23 and 33 days is 0.23 in the inbred stock and 0.35 in the control stock.

For the inbreds the coefficient of correlation between total gain from birth to 33 days and monthly weights from 33 days to 353 days gradually decreases from 0.95 at 33 days to 0.42 at 353 days and 0.33 at 713 days, or approximately 2 years of age. For B stock the correlation at 33 days is also 0.95, but for weights after 113 days the correlations are somewhat higher than in the inbreds. (Table 12 and fig. 12.) The correlations discussed are shown graphically in Figures 11 and 13.

After 83 days there is a lack of correlation among early and later gains, as the correlations fluctuate between low plus values

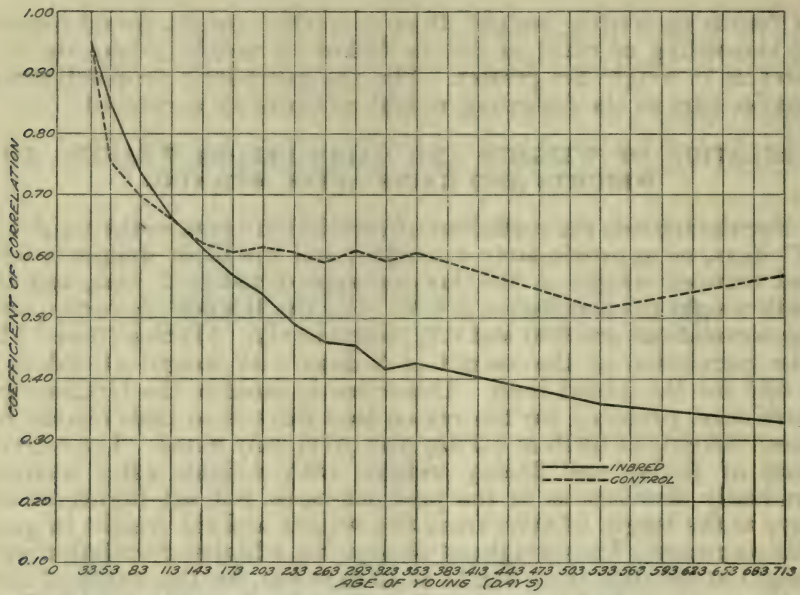

FIGURE 12.—Coefficient of correlation between gain from birth to 33 days and weights at later ages in the average of five inbred families and the control stock of guinea pigs

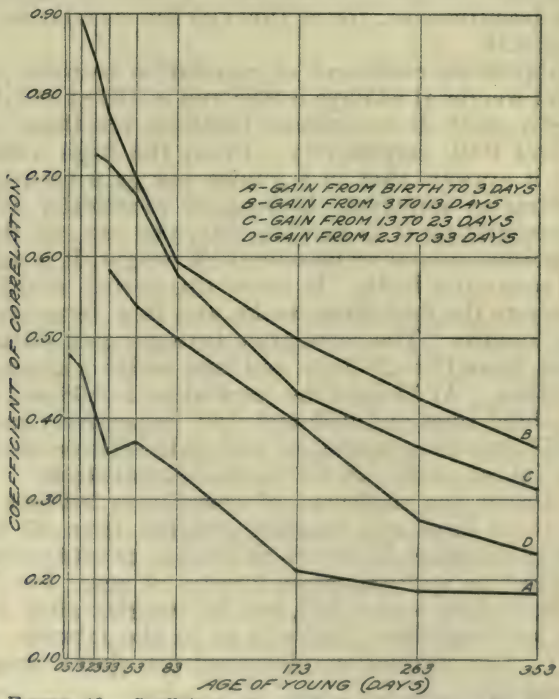

FIGURE 13.—Coefficient of correlation between gains at different periods, with weights at the ages indicated in the average of five inbred lines of guinea pigs

and minus values. There is little or no correlation between gains from birth to weaning and gains after 53 days. (Table 13.) The foregoing results show that up to about 2 months of age there is an appreciable correlation among gains, but there is no assurance that a guinea pig which gains well up to weaning will continue to make good gains to maturity.

TABLE 12.—*Correlation of gain from birth to 33 days of age with weights at ages indicated*

Age (days)	Inbred stock (946 animals)	Control stock (113 animals)	Age (days)	Inbred stock (946 animals)	Control stock (113 animals)	Age (days)	Inbred stock (946 animals)	Control stock (113 animals)
33	+0.95	+0.95	173	+0.57	+0.60	323	+0.41	+0.59
53	.85	.75	203	.54	.61	353	.42	.60
83	.74	.70	233	.49	.60	533	[1].36	[2].51
113	.66	.63	263	.46	.59	713	[3].33	[4].57
143	.61	.62	293	.45	.61			

[1] 641 animals used. [2] 85 animals used. [3] 440 animals used. [4] 68 animals used.

TABLE 13.—*Correlation of gain from birth to 33 days of age with gains at periods indicated*

Period of gain (days)	Inbred stock (946 animals)	Control stock (113 animals)	Period of gain (days)	Inbred stock (641 animals)	Control stock (85 animals)	Period of gain (days)	Inbred stock (440 animals)	Control stock (68 animals)
33–53	+0.30	+0.21	353–383	−0.03	+0.01	533–563	−0.02	0.00
53–83	.00	+.14	383–413	+.04	−.27	563–593	−.03	−.02
83–113	−.14	−.09	413–443	−.09	+.02	593–623	+.03	+.29
113–143	−.18	−.03	443–473	−.02	−.05	623–653	+.03	−.13
143–173	−.11	+.07	473–503	−.07	+.02	653–683	+.02	−.06
173–203	−.03	+.07	503–533	+.02	−.11	683–713	−.07	+.35
203–233	−.10	−.04						
233–263	−.03	.00						
263–293	−.01	−.04						
293–323	−.03	+.06						
323–353	−.02	+.05						

In a comparison of the values of η and r in the correlations between gains and following weights, it was found that the values agree very closely to about 1 year of age, after which they differ considerably but continue to run approximately parallel. These comparisons were made for gain from birth to 33 days, 33 days to 53 days, and 53 days to 83 days and the weights taken at later dates in families 2, 13, 35, and in stock B. There is very little difference in any of these groups. This shows that a nearly linear relationship exists between the gains made during the three periods named above and the later weights. The test for linearity is denoted by ζ where $\zeta=\eta^2-r^2$. The significance of this value is expressed by $\sigma\zeta=2\sqrt{\frac{\zeta}{N}}$, in which N is the number of individuals entering into the correlations. Only those cases were tested in which the graphs showed the widest departure, and in none of the inbreds was ζ found to be significant, the values of $\sigma\zeta$ being not more than twice the value of ζ. In B stock the differences were larger, but even there the values of $\sigma\zeta$ did not

exceed three times the value of ζ. Comparisons of η and r values for family 2, which is representative of the other families, are shown in Figure 14.

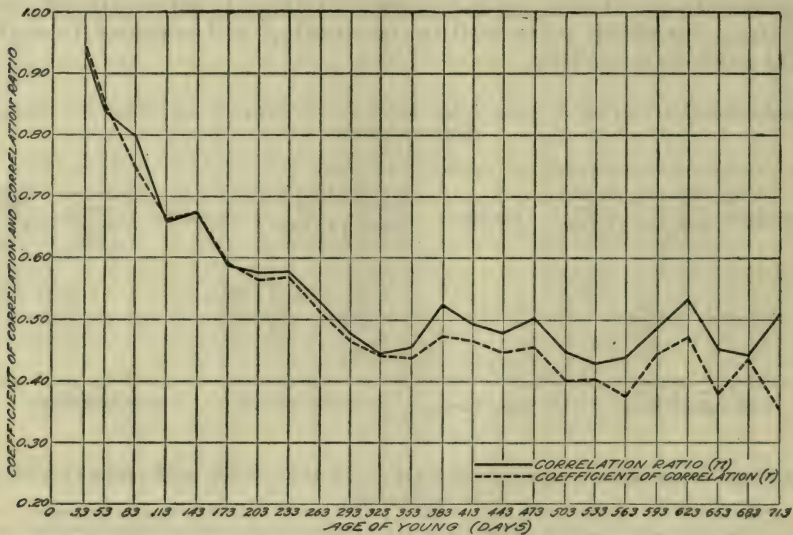

FIGURE 14.—Comparison of coefficient of correlation (r) and correlation ratio (η) between gain from birth to 33 days and weights at later ages in inbred family 2

A comparison of the values of η and r was made between gain correlations similar to the ones between gain and weight mentioned previously. The same gains, i. e., gain between birth and 33 days,

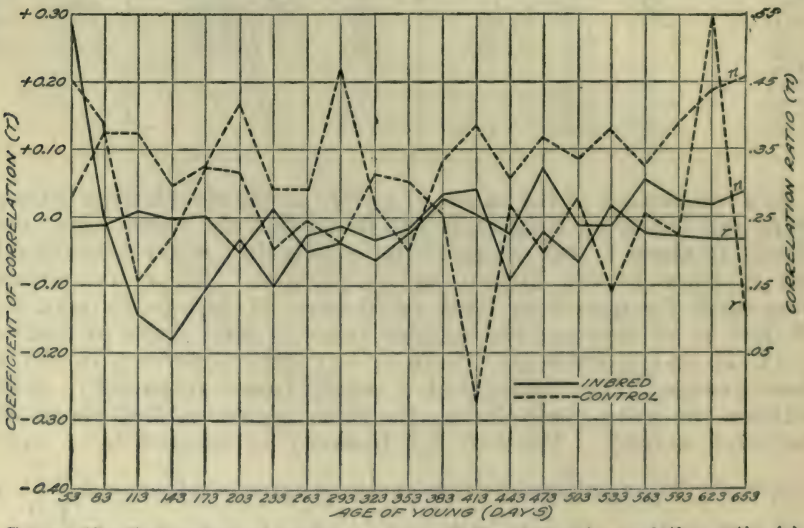

FIGURE 15.—Comparison of coefficient of correlation (r) and correlation ratio (η) between gain from birth to 33 days and later gains in the average of five inbred lines and the control stock of guinea pigs

33 and 53, and 53 and 83 days, were correlated with all gains following these periods. Here the values of η and r were considerably different, but the parallelism between them seems to indicate lack

of correlation. The comparative correlation values of η and r for inbreds and controls are shown in Figure 15.

A consideration of the correlations in the different families shows few differences. In the correlation between gain to 3 days and weights taken later, family 13 has the highest correlations at 13, 53, and 83 days, it being higher even than the correlations for stock B for the same periods. For the gain from 3 to 13 days family 13 has the highest correlation of any of the inbred or control stock at 23, 33, 53, and 83 days, and for the gain between 13 and 23 days the same family has the highest correlations at 23, 33, and 53 days. This is probably the result of the similar rate of growth of family 13 and the other lines including B during these periods as shown by McPhee and Eaton (*14*). Family 13 grows very rapidly, and although perhaps not so heavy as the B stock through these early periods, catches up to and surpasses B stock in weight from about 2 to 5½ months.

DISCUSSION

FACTORS AFFECTING LITTER SIZE

The condition of the dam as expressed by age and weight was found to be an important factor in determining size of litter in guinea pigs. In general, the size of litter in the inbred lines increases until the dam reaches 12 to 16 months of age, and then decreases. In the control stock B the maximum size of litter is reached when the dams are about 18 months old. This is probably due to the longer growth period of the B stock. The correlation of age of dam to litter size is 0.19 in the inbred stock and 0.31 in the control stock, probably indicating that litter size is more uniform in the inbred lines and less influenced by the dam's age than in the control stock.

The correlation of dam's weight to litter size is higher than the correlation of age to litter size in both the inbred and control stock. The correlation of dam's weight to litter size is 0.26 in the inbred lines and 0.34 in the control stock. The true relation is probably not in weight by itself but in general physical condition of the dam, which is reflected to a large extent through her weight.

Since age of dam has a high correlation to litter rank, the correlation of litter rank to litter size should be practically the same as the correlation between dam's age and litter size. This was found to be the case, being 0.18 for the inbreds and 0.32 for the control stock.

The effect of season of year on litter size takes place at time of conception. There is a slight seasonal variation in litter size, the largest litters being born late in the summer or in the fall when the feed and temperature conditions about two months before the birth of the litter were favorable.

Heredity influences to a certain extent the size of litter, as shown by the variation in the different inbred lines and the control stock, but not so much as might generally be expected. Among several characteristics studied in guinea pigs, it was found that litter size was less variable than weight. Therefore, heredity is a smaller factor in determining litter size than weight, and the inbred lines still show 77 per cent as much variability in litter size as the control stock.

FACTORS AFFECTING BIRTH WEIGHT

It has been shown previously that heredity determines to a large extent the birth weight of a guinea pig and that seasonal conditions and feed play a lesser part, feed, however, probably having more influence than season of the year in which a guinea pig is born.

In both the inbred and control stock the condition of the dam, as expressed by her weight and age, was found to exert an influence on the birth weight of the young, but the weight of the dam had more effect than her age. If the dam's weight is kept constant, the partial correlation between birth weight of young and age of dam is only −0.06, whereas when age is constant, the partial correlation of birth weight of young with dam's weight is 0.31. In determining weight of the young, therefore, it is more important to select females of the average weight for their breed or family than to select for age. Likewise, on litter size, the dam's weight exerts a greater influence than does her age, the partial correlation with constant age being 0.18, whereas with constant weight, the partial correlation is 0.03. This also shows that weight of dam with constant age has less effect on litter size than it does on birth weight of young under the same conditions, whereas age of dam with constant weight has a greater effect in determining litter size than it does birth weight.

In the relation of the factors, birth weight, weight of dam, and litter size, litter size plays a larger part than does dam's weight in determining birth weight of young, the partial correlation being −0.79 when the dam's weight is constant and 0.67 when litter size is constant. Birth weight of young was found to be also highly correlated with length of gestation period, and this in turn with litter size. When length of gestation period is constant, the partial correlation of birth weight with litter size is −0.55, and when litter size is constant the partial correlation with gestation period is 0.23. By multiple correlation and path coefficients it was found that the two factors, litter size and gestation periods taken together, determine about 64 per cent of the birth weight; age of dam, and litter rank together determine about 4 per cent; and age and weight of dam determine about 12 per cent.

Since the effect of age of dam on birth weight is so slight, the three factors, weight of dam, length of gestation period, and litter size are considered as the principal factors affecting birth weight aside from the prenatal growth rate. Even these three factors determine only 68 per cent of the birth weight in the inbred stock. In the control stock they determine 84 per cent of the birth weight. This is more than would naturally be expected, and an explanation of it is necessary. It was noted that correlations in the B stock were higher in most cases than in the inbred stock. One would expect correlations to be higher in the inbred stock since inbreeding reduces variability of weights and litter size, birth weight being only 73 per cent as variable as in the B stock and litter size 88 per cent as variable. In the data taken, however, it was observed that the age of dam, weight of dam, and length of gestation period were more variable in the inbred stock than in the control. This is due to the fact that only the more vigorous animals were mated

in the B stock, whereas in the inbreds, brothers and sisters were mated, regardless of their vigor unless it was obvious they would die within a short time. Therefore, the variability in their weights was greater than in the weights of the B stock animals that were mated.

In the inbred stock it is the custom to mate litter mates as far as possible, but in several cases, especially in families 35 and 39, old females have been mated to young males and vice versa, in order to advance certain generations. In the control stock the males and females were as near the same age as possible, but no animals more closely related than second cousins were mated. Thus there should be less variability in the ages among the inbred females. The apparent less variability in the ages of the females of the control stock is probably due to the greater regularity of breeding, the litters of which come at more consecutive ages of the dam than among the inbred stock where two or more oestrus periods between successive litters are often skipped.

Apparently inbreeding has made length of gestation period more variable than it is in the control stock. Just why this results is not apparent unless inbreeding influences some physiological factors which cause the dam to expel the fetuses more irregularly. The fact that there is a larger percentage of premature births in the inbreds than in the control stock seems to bear this out.

In correlating the different variables it is assumed that the variability of B stock is normal in all factors. In the inbreds, however, birth weight of young, for example, has been reduced in variability whereas weight of dam has become more variable under the conditions of the experiment. This makes the correlation lower in the inbreds than in the control stock. However, the differences in the correlations are not statistically significant. When the correlation is made between two variables both of which are reduced, as litter size and birth weight, the correlation will not be altered if there is proportionate change in the two factors concerned. This appears to be the case, for the correlation values of litter size and weights, birth weight and later weights, and gains and later weights are closer between the inbred and control stocks than are the correlation values of age or weight of dam and any of the weight factors. The differences between the correlation values are not statistically significant.

FACTORS AFFECTING GAINS AND WEIGHTS BEFORE WEANING

Since gain from birth to weaning is dependent mostly on the ability of the young themselves to get food, only weight and age of dam are considered as contributory influences. They have nearly the same influence in both the control and inbred stocks. Weight of dam determines 9 per cent of the total gain to weaning in both stocks of guinea pigs, and age of dam determines 7 per cent for the inbreds and 8 per cent for the controls.

Gain between birth and 3 days of age is correlated with gains during the following three 10-day periods up to weaning at 33 days. The first 3-day gain determines the gain during the next 10 days by 10 per cent in the inbreds and 11 per cent in the B stock. The first 3-day gain determines the gain during the second 10-day period

by only 3 per cent in the inbreds and 7 per cent in the B stock. The relation remains practically unchanged in the inbred stock for the gain during the third 10-day period, but in the B stock there is practically no dependence whatever on the first 3-day gain.

Gain between 3 and 13 days has more effect on the later gains to weaning than does the first 3-day gain, as in the inbred stock it determines about 18 per cent of the gain for the period from 13 to 23 days and 4 per cent for the period from 23 to 33 days. The determination for the two corresponding periods in the B stock is 7 and 4 per cent, respectively.

The weights during any period between birth and weaning are, of course, dependent on the gains during any of these periods. Gain during the first 3 days determines 13 per cent of the weight at 33 days in the inbreds and 22 per cent in the control stock. The 10-day period from 3 to 13 days apparently determines, more than any other gain, the weight at 33 days, as it determines 61 per cent of the weight of the inbred and 66 per cent of that of the control stock. The gain during the 10 days immediately preceding weaning determines weaning weight by only 34 per cent in the inbreds and 24 per cent in the B stock. From these facts it is evident that the gains to weaning have very little dependence on the dam, either on her age or weight. Gains during different 10-day periods between birth and weaning do have considerable dependence on one another. The period of greatest importance between birth and weaning seems to be that between 3 and 13 days. It is during this period that the guinea pig apparently recovers from readjustment from prenatal to postnatal life, that readjustment taking place during the first three days after birth. It was found that gains during this period were very low or even negative in many cases. In the 3 to 13 day period the guinea pig is able to obtain its own food supply and thus get well started in growth.

FACTORS AFFECTING GAINS AND WEIGHTS AFTER WEANING

In the group of animals whose early weights and gains were recorded, the correlation between birth weight and weaning weight was 0.71 and 0.72 in the inbreds and B stock, respectively, thus making weaning weight 50 per cent dependent on birth weight. At 83 days, or practically 3 months of age, the weight is only about 25 per cent dependent on the birth weight. In the inbreds birth weight determines about 12 per cent of the weight at 1 year of age and in stock B about 22 per cent. Weight at 3 days of age has practically the same determination of any future weight as has birth weight because of the small change between birth and 3 days, as has been mentioned previously. Weight at 13, 23, and 33 days each determines to an increasing extent later weights. At 173 days, 13-day weight has a determination of 30 per cent in both inbreds and B stock, and the percentage is only slightly less at 353 days. At 173 days, 23-day weight determines about 36 per cent of the weight in both stocks. At 353 days it determines 18 per cent of the weight of the inbreds and 31 per cent of the weight of the controls. In the group in which weights between birth and 33 days were not recorded, weaning weight determines about 38 per cent of the weight at 173 days for

both stocks, practically the same percentage at 353 days for B stock and 21 per cent for the inbreds. The percentage for B stock changes only slightly at 533 days and 713 days, whereas for the inbreds the percentages were 16 and 9 per cent, respectively, for these periods.

It was found that the gain during the first three days had little effect on later weights up to weaning. The same is true of weights after weaning. Gain between birth and 3 days of age determines only 11 per cent of the weight at 83 days in the inbreds and 8 per cent in the control stock. At 173 days the determinations are 4 and 8 per cent, respectively, and at 353 days 3 and 15 per cent. The 10-day gain from 3 to 13 days seems to be the most important in the determination of weights to 1 year of age, and the effect in the inbred and control stocks is closer at this period apparently than in others, perhaps because of a greater uniformity in the rate of gains during this period. At 83 days the gain between 3 and 13 days in both stocks determines 35 per cent of the weight, at 173 days 25 per cent, and at 353 days 13 and 15 per cent in the inbreds and B stock, respectively. The gain between 13 and 23 days is about as uniform in its influence and only slightly less in percentage effect on future weights as gain from 3 to 13 days. The effect is about 2 per cent less on the weight at 83 days of age, 6 per cent less at 173 days of age, and nearly the same at 353 days of age. The gain from 23 to 33 days is more variable and less in magnitude in its effect on weights at different periods, than those preceding it. At 83 days the determination is 24 per cent in both stocks, at 173 days 15 and 13 per cent in the inbreds and controls, respectively, and at 353 days 5 and 12 per cent, respectively.

Total gain from birth to weaning has a greater effect up to 113 days of age in determining the weights of the inbreds than of the B stock; the same effect, at 143 days, in determining the weights of both stocks; and a slightly greater effect, after 143 days, in determining the weight of the B stock. At 83 days the weight is 54 per cent dependent on the gain between birth and weaning in the inbreds and 49 per cent in the B stock. At 173 days the weight is dependent on this gain, 32 and 36 per cent in the inbreds and controls, respectively, and at 353 days, 18 and 36 per cent. The influence continues high in the B stock, being more than 25 per cent at 533 days and at 713 days, whereas in the inbreds the influence is only 13 and 11 per cent at these ages.

When the different inbred lines are considered separately as to extent of correlation between weights and between gains and weights, there is considerable variation. However, in ranking the families as to highest and lowest correlation values, family 35 has the highest correlation between any weight and its later weights, whereas family 39 has the lowest correlation. When gain is correlated during any of the early periods before weaning with later weights, family 13 has the highest correlation and family 39 the lowest. Total gain from birth to weaning correlated with later weights to 713 days is highest in family 35 and lowest in family 39. In both groups of gain correlations family 2 holds second place. It will be noted that family 39 held lowest place in all three groupings, a fact which probably indicates greater variability in weights and gains than in the other families, or less relationship between these factors.

SUMMARY AND CONCLUSIONS

The birth weight of guinea pigs is influenced more by the feed the dam is receiving than by season of the year. Size of the litter is more influenced by season of the year than it is by feed.

Condition of the dam, as measured by her age and weight, influences only slightly any of the factors affecting the young included in this study. Dam's age has a greater influence in determining litter size than in determining weight of young. On the other hand, dam's weight has a greater influence on the weight of the young than it has on litter size. Age and weight of dam together determine about 12 per cent of the birth weight.

The factors on which birth weight is most dependent are litter size and length of gestation period, which, taken together, determine more than 60 per cent of the birth weight.

Mortality varies with litter rank, the percentages born alive increasing to about the fourth or fifth litter, then gradually decreasing. Of the young raised of those born alive, the percentage gradually increases to about the eighth litter and then rapidly decreases.

There is very little correlation between size of first litter and size of later litters and likewise between weight of young in first litter and weight of young in later litters. Thus first litters seem to be a poor indication of what a female will produce later.

Weights at birth are correlated with all later weights, but the correlation decreases as maturity is approached.

Gains are likewise correlated with all later weights, but the farther removed the weight from the gain concerned, the lower the correlation. The period of gain having the highest correlation with all later weights was that between 3 and 13 days of age, indicating that rapid early growth is important in determining mature weights. The following 10-day growth period is only slightly less so.

There is very slight or no correlation between gain at different periods.

Inbreeding does not necessarily increase the correlation among various factors. Variability may be reduced in both variables correlated, but proportionately in each direction, thus leaving the correlation unchanged. In other cases one variable may be reduced more than another, and the correlation may be lower in the inbred than in the control stock.

LITERATURE CITED

(1) BRODY, S.
1927. GROWTH AND DEVELOPMENT WITH SPECIAL REFERENCE TO DOMESTIC ANIMALS. VI. GROWTH RATES DURING THE SELF-INHIBITING PHASE OF GROWTH. Missouri Agr. Expt. Sta. Research Bul. 101. 26 p., illus.

(2) CARMICHAEL, W. J., and RICE, J. B.
1920. VARIATION IN FARROW: WITH SPECIAL REFERENCE TO THE WEIGHT IN PIGS. Ill. Agr. Expt. Sta. Bul. 226, p. 67–95, illus.

(3) ECKLES, C. H.
1919. A STUDY OF THE BIRTH WEIGHT OF CALVES. Missouri Agr. Expt. Sta. Research Bul. 35, 11 p., illus.

(4) HAINES, G. H.
1931. A STATISTICAL STUDY OF THE RELATION BETWEEN VARIOUS EXPRESSIONS OF FERTILITY AND VIGOR IN THE GUINEA PIG. Jour. Agr. Research 42: 123–164, illus.

(5) HAMMOND, J.
1914. ON SOME FACTORS CONTROLLING FERTILITY IN DOMESTIC ANIMALS. Jour. Agr. Sci. [England] 6: 263–277.
(6) IBSEN, H. L.
1928. PRENATAL GROWTH IN GUINEA PIGS, WITH SPECIAL REFERENCE TO ENVIRONMENTAL FACTORS AFFECTING WEIGHT AT BIRTH. Jour. Expt. Zool. 51: 51–91, illus.
(7) JONES, S. V. H., and ROUSE, J. E.
1920. THE RELATION OF AGE OF DAM TO OBSERVED FECUNDITY IN DOMESTIC ANIMALS. MULTIPLE BIRTHS IN CATTLE AND SHEEP. Jour. Dairy Sci. 3: 260–290, illus.
(8) KING, H. D.
1915. ON THE WEIGHT OF THE ALBINO RAT AT BIRTH AND THE FACTORS THAT INFLUENCE IT. Anat. Rec. 9: 213–231.
(9) ———
1917. THE RELATION OF AGE TO FERTILITY IN THE RAT. Anat. Rec. 11: 269–287, illus.
(10) ———
1927. SEASONAL VARIATIONS IN FERTILITY AND IN THE SEX RATIO OF MAMMALS, WITH SPECIAL REFERENCE TO THE RAT. Ztschr. Wiss. Biol. (Abt. D) Arch. Entwickl. Mech. Organ. 112: 61–111, illus. [Summary in German p. 107–109.]
(11) KOPEĆ, S.
1924. ON THE INFLUENCE EXERTED BY CERTAIN INHERITANCE FACTORS ON THE BIRTH WEIGHT OF RABBITS. Anat. Rec. 27: 95–118.
(12) ———
1923. SUR L'HÉRÉDITÉ DU POIDS DES LAPINS D'APRES L'ÉTUDE DES NOUVEAU-NÉS. Pam. Państ. Inst. Nauk. Gosp. Wiejsk. Pulawach (Mém. Inst. Natl. Polon. Econ. Rurale Pulawy) 4: [218]–243. [In Polish. Résumé in French, p. 241–243.]
(13) ———
1925. ON THE CORRELATION BETWEEN THE WEIGHT OF NEW-BORN AND THAT OF GROWING AND OF FULL-GROWN RABBITS. Pam. Państ. Inst. Nauk. Gosp. Wiejsk. Pulawach (Mém. Inst. Natl. Polon. Écon. Rurale Pulawy) 6: [288]–329. [In Polish. Summary in English, p. 325–329.]
(14) MCPHEE, H. C., and EATON, O. N.
1930. GENETIC GROWTH DIFFERENTIATION IN GUINEA PIGS. U. S. Dept. Agr. Tech. Bul. 222, 36 p., illus.
(15) MINOT, C. S.
1891. SENESCENCE AND REJUVENATION. Jour. Physiol. 12: 97–153, illus.
(16) WRIGHT, S.
1921. CORRELATION AND CAUSATION. Jour. Agr. Research 20: 557–585, illus.
(17) ———
1922. THE EFFECT OF INBREEDING AND CROSSBREEDING ON GUINEA PIGS. I. DECLINE IN VIGOR. II. DIFFERENTIATION AMONG INBRED FAMILIES. U. S. Dept. Agr. Bul. 1090, 63 p., illus.
(18) ———
1922. THE EFFECTS OF INBREEDING AND CROSSBREEDING ON GUINEA PIGS. III. CROSSES BETWEEN HIGHLY INBRED FAMILIES. U. S. Dept. Agr. Bul. 1121, 61 p., illus.
(19) ——— and EATON, O. N.
1929. THE PERSISTENCE OF DIFFERENTIATION AMONG INBRED FAMILIES OF GUINEA PIGS. U. S. Dept. Agr. Tech. Bul. 103, 46 p., illus.

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UNITED STATES DEPARTMENT OF AGRICULTURE
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RELATION OF THE METHOD OF WATERING DAIRY COWS TO THEIR WATER CONSUMPTION AND MILK PRODUCTION

By T. E. WOODWARD, *Senior Dairy Husbandman*, and J. B. MCNULTY,[1] former *Dairy Husbandman, Division of Dairy Cattle Breeding, Feeding, and Management, Bureau of Dairy Industry*

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INTRODUCTION

When dairy cows are on pasture they usually have access to drinking water at all times, but when they are stabled the number of times a day they are permitted to drink may vary considerably. Some farmers set up individual drinking cups in the stalls, which make it possible for the cows to drink at will, whereas other dairymen turn the cows out of their stalls to drink, either once or twice a day, from troughs outside or inside the barn.

Investigators disagree regarding the effect of frequency of watering upon milk production. Backhaus (*1*, *3*)[2] reports that in one experiment in Germany, cows drinking at will gave 0.53 liter (0.56 quart) more milk per cow per day than when watered twice a day, and in another experiment such cows gave 0.61 kilogram (1.34 pounds) more milk. In the first experiment in which the cows were watered at will they drank less water than when drinking twice a day; in the second experiment they averaged 1.7 liters (1.8 quarts) more water a day.

Hayward (*4*), in describing work at the Pennsylvania Agricultural Experiment Station, states that cows, when turned into the yard for water once a day, produced as well as when they had constant access to water in the stable.

[1] Resigned.
[2] Italic numbers in parentheses refer to Literature Cited, p. 13.

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Hills (*5*) concludes from experiments at the Vermont Agricultural Experiment Station that no more and no better milk was produced when the cows drank at will than when they drank twice a day.

Larsen and others (*6*) at the South Dakota Agricultural Experiment Station found that when four cows were watered once a day instead of every eight hours their milk production decreased nearly 2 pounds a day.

In experiments in England (*2*) in which cows had constant access to water in drinking cups the animals gave approximately 1 per cent more milk than when they were watered once or twice a day.

Cannon [3] found that at the Iowa Agricultural Experiment Station cows given free access to water in drinking cups produced 6.14 per cent more milk and 12.12 per cent more butterfat than when offered water twice a day at outside drinking troughs. When getting water from the cups the cows drank 18.37 per cent more than when watered outside.

Experiments have been carried on at the United States Dairy Experiment Station at Beltsville, Md., by the Bureau of Dairy Industry, to determine the effects of frequency of watering dairy cows, both in warm and cold weather and at different times of the day, on their production of milk and butterfat. Both high-producing cows and low-producing cows were included in the tests. The results of this work are given in this bulletin.

FREQUENCY OF WATERING

PLAN OF EXPERIMENTS

Three 90-day experiments, each of which was divided into three 30-day periods, were made (Table 1) to determine the effect of frequency of watering on the quantity of water drunk, on the quantity of milk produced, and on the weight of the cows. A different group of cows was used in each experiment.

At the end of each 30-day period the frequency of watering was changed, as shown in Table 1, five days being allowed to accustom the cows to the new method of watering. Two cows were used in each experiment for testing each of the three methods of watering, making a total of 18 cows. One cow aborted early in the second period of the third experiment and was dropped from the experiments. Another

TABLE 1.—*Plan of experiments to determine effect of frequency of watering on the quantity of water drunk, milk produced, and the weight of the cows*

Group No.	Frequency of watering in—		
	Period 1	Period 2	Period 3
1	Once daily	Twice daily	From cups (at will).
2	Twice daily	From cups (at will)	Once daily.
3	From cups (at will)	Once daily	Twice daily.

[3] Cannon, C. Y. INFLUENCE OF WATER BOWLS ON WATER CONSUMPTION OF DAIRY COWS. Paper presented at 25th Annual Meeting, Amer. Dairy Sci. Assoc., Ames, Iowa, June 24–26, 1930. [Not published. Title in Program, also in Jour. Dairy Sci. 13: 534. 1930.]

cow used in the second experiment developed a habit of licking up water while using the cup, which resulted in so large a loss of water that it was necessary to omit her record. Consequently, complete records were obtained for only 16 cows.

Each cow was fed all the hay and silage she would eat without waste, and also grain at the rate of 10 pounds for each pound of butterfat produced, the allowance being calculated from her average daily production during the preceding 10-day period. Half the silage and grain was fed at 4 a. m. and the other half about 2 p. m. Usually the hay was fed about 4.30 p. m.

The water for the individual drinking cups flowed from a 5-gallon glass carboy inverted in a bowl of water connected with the drinking cup. A metal lid over each cup excluded foreign matter. Although the cow raised the lid in drinking, the lid dropped over the bowl when she had finished.

Except for about two hours each forenoon when the cows were turned out to exercise, they were confined in individual stalls in the barn. The maximum and minimum air temperatures in the barn were recorded daily by a self-registering thermometer hung on the wall. In the last two experiments the maximum and minimum temperatures of the water in the drinking cups were recorded daily by a self-registering thermometer immersed in one of the cups. In these experiments, also, the temperature of the water offered to the cows when watered once or twice a day was recorded once daily. This water came from a faucet in the barn and varied only slightly in temperature from day to day.

Cows permitted to drink but once a day were offered water at 7 a. m.; those permitted to drink twice were offered water at 7 a. m. and 5 p. m. in the first experiment and at 7 a. m. and 7 p. m. in the last two experiments. The quantity of water drunk by the cows using individual cups was also determined at these hours. A large galvanized tub, placed on a platform scale in one corner of the barn, contained the water for the cows permitted to drink once and twice daily. When the hour for watering arrived, each cow was driven to this corner and compelled to remain there for several minutes, even if she gave no indications of wanting water. Only fresh, clean water was offered, the tub being emptied after each drinking.

In calculating the butterfat, tests were made of samples of milk taken for two consecutive days during every 10 days of the experiment.

EXPERIMENTS WITH LOW-PRODUCING COWS

LOW-PRODUCING COWS WATERED IN WARM WEATHER

The first experiment was conducted from July 22 to October 31, inclusive. Six cows were used (1 grade Holstein, 2 grade Jerseys, 1 registered Holstein, and 2 registered Guernseys). The daily milk production was rather low, varying during the experiment from only 7.1 pounds to 24.3 pounds per cow. Four to ten pounds of clover hay and 27 to 46 pounds of silage were fed daily to each cow, the quantity depending upon the size of the animal. The results of this experiment are given in Table 2, which shows that the quantity of water drunk by different cows varied from 42 to 107 pounds per day.

TABLE 2.—*Effect of frequency of watering low-producing cows in warm weather July 22–October 31*

Cow No.	Watered from individual cups at will				Watered at 7 a. m. and 5 p. m.				Watered at 7 a. m.			
	Water drunk daily	Daily production		Daily gain or loss in weight	Water drunk daily	Daily production		Daily gain or loss in weight	Water drunk daily	Daily production		Daily gain or loss in weight
		Milk	Butterfat			Milk	Butterfat			Milk	Butterfat	
	Period 3				Period 2				Period 1			
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
51	54	11.6	0.46	1.0	67	14.7	0.53	0.3	86	18.9	0.56	−1.0
100	42	7.8	.37	.6	54	9.5	.39	−.3	64	11.4	.45	−.7
	Period 2				Period 1				Period 3			
111	63	12.7	0.79	1.5	79	14.7	0.75	−.8	43	9.8	0.62	0.5
204	83	22.0	.72	−.7	107	24.3	.75	1.0	69	18.7	.65	1.7
	Period 1				Period 3				Period 2			
19	68	17.4	0.77	−.8	47	11.0	0.65	.5	55	13.8	0.68	0.4
34	67	11.7	.39	−.4	45	7.1	.40	.8	42	9.7	.46	1.2
Average	63	13.9	.58	.2	66	13.5	.58	.2	60	13.7	.57	.3

If 100 is used to denote the quantity of water drunk and milk produced by the cows watered from cups, the relative quantities for the other two groups would be those shown in Table 3.

TABLE 3.—*Relative quantities of water drunk and milk produced with different frequencies of watering low-producing cows in warm weather*

	Frequency of watering		
	From cups (at will)	Twice daily	Once daily
Water drunk	100	106	95
Milk produced	100	98	99

During this experiment there were several intensely warm days, the thermometer registering 97° F. on July 31. The average maximum and minimum temperatures in the barn were as follows: First period, 86.5° and 69.4°; second period, 75.8° and 60.4°; and third period, 64.1° and 45.9°. The quantity of water drunk was greatest during the first 30-day period, when the temperatures were highest, regardless of the method of watering. In comparing the methods of watering, the possible error due to differences in temperature was avoided by carrying on experiments with all three methods simultaneously.

LOW-PRODUCING COWS WATERED IN COLD WEATHER

The second experiment differed from the first in only one important particular, namely, temperature. It was conducted from January 3

to April 14, in much colder weather than that in the first experiment. The average maximum and minimum temperatures in the barn were as follows: First period, 45.7° and 36.6° F.; second period, 56° and 44.3°; and third period, 60.5° and 49.4°.

Data were obtained on only five cows, as one cow developed the habit of licking water from the cup and was dropped from the experiment. Two grade Guernseys, a grade Holstein, a registered Holstein, and a registered Guernsey were used. As in the first experiment, the cows were rather low producers, the daily milk yield during this second experiment varying from 10.9 to 21.6 pounds. Five pounds of clover hay and 30 to 50 pounds of corn silage were fed each cow per day, the quantity depending on the size of the animal.

The results of the second experiment are given in Table 4, which shows that the average quantity of water drunk daily by different cows varied from 27 to 63 pounds. In the first experiment, when the weather was warmer, cows producing similar quantities of milk drank 42 to 107 pounds per day.

TABLE 4.—*Effect of frequency of watering low-producing cows in cold weather (January 3–April 14)*

Cow No.	Watered from individual cups at will				Watered at 7 a. m. and 5 p. m.				Watered at 7 a. m.			
	Water drunk daily	Daily production		Daily gain in weight	Water drunk daily	Daily production		Daily gain or loss in weight	Water drunk daily	Daily production		Daily gain or loss in weight
		Milk	Butterfat			Milk	Butterfat			Milk	Butterfat	
	Period 3				Period 2				Period 1			
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
33	33	10.9	0.57	0.7	35	11.6	0.61	1.1	27	11.7	0.61	−0.3
114	47	15.1	.68	1.1	48	15.0	.63	.6	39	15.7	.65	−.8
	Period 2				Period 1				Period 3			
50	58	20.6	0.85	0.5	52	21.6	0.81	0.1	52	20.8	0.81	0.6
44	45	12.7	.63	.2	38	13.5	.66	−.1	38	11.8	.58	1.4
	Period 1				Period 3				Period 2			
212	63	17.8	0.65	1.1	57	15.5	0.63	−0.1	54	15.8	0.66	1.8
Average	49	15.4	.68	.7	46	15.4	.67	.3	42	15.2	.66	.5

The relative quantities of water drunk and milk produced (obtained in the same way as the data in Table 3) are shown in Table 5.

TABLE 5.—*Relative quantities of water drunk and milk produced with different frequencies of watering low-producing cows in cold weather*

	Frequency of watering		
	From cups (at will)	Twice daily	Once daily
Water drunk	100	94	85
Milk produced	100	100	98

EXPERIMENTS WITH GOOD PRODUCERS

On account of the low production of the cows used in the first and second experiments, it was decided to conduct an experiment with higher producers. The production of these cows (six registered Holsteins) ranged from 21.4 to 41.5 pounds per day. The experiment was conducted from December 8 to March 28. The average maximum and minimum temperatures of the atmosphere in the barn were as follows: First period, 55.7° and 39.9° F.; second period, 51.3° and 40.9°; and third period, 60.5° and 45.5°.

As one of the cows aborted, data are given for only five cows. From 5 to 12 pounds a day of alfalfa or clover hay and from 20 to 40 pounds of silage were fed per cow per day, the larger cows receiving the greater quantities. The results of this experiment are given in Table 6, which shows that the individual cows averaged from 68 to 100 pounds of water per day, whereas those in the second experiment, yielding only about half as much milk, drank 27 to 63 pounds of water. These figures, however, are not exactly comparable, because the cows in the third experiment ate more hay and less silage than those in the second.

TABLE 6.—*Effect of frequency of watering on good cows in cold weather (December 8–March 28)*

Cow No.	Watered from individual cups at will				Watered at 7 a. m. and 5 p. m.				Watered at 7 a. m.			
	Water drunk daily	Daily production		Daily gain in weight	Water drunk daily	Daily production		Daily gain or loss in weight	Water drunk daily	Daily production		Daily gain or loss in weight
		Milk	Butterfat			Milk	Butterfat			Milk	Butterfat	
	Period 2				Period 3				Period 1			
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
201	90	40.2	1.24	0.1	98	37.7	1.20	0.4	85	41.5	1.32	−2.2
243	82	26.5	.80	1.0	90	25.0	.76	.8	83	25.2	.69	−.6
	Period 3				Period 1				Period 2			
217	[1]											
244	85	28.5	1.16	1.1	100	28.2	0.99	−.7	68	26.8	1.09	−.2
	Period 1				Period 2				Period 3			
228	93	36.5	1.21	1.2	78	35.8	1.36	1.6	69	32.9	1.13	1.4
242	86	25.8	.77	0	78	24.0	.83	1.7	74	21.4	.76	1.6
Average	87	31.5	1.04	.7	89	30.1	1.03	.8	76	29.6	1.00	0

[1] Aborted.

The relative quantities of water drunk and milk produced (expressed in the same way as in Table 3) are shown in Table 7.

TABLE 7.—*Comparison of quantity of water drunk and milk produced with different frequencies of watering good cows in cold weather*

	Frequency of watering		
	From cups (at will)	Twice daily	Once daily
Water drunk	100	102	87
Milk produced	100	96	94

A comparison of this table with Tables 3 and 5 shows that the increase in milk production due to more frequent watering was more marked in the case of the good producers than in the case of the low producers.

In the third experiment good-producing cows drinking at will averaged 4 per cent more milk than when watered twice a day and 6 per cent more milk than when watered once a day, whereas in the two preceding experiments with low-producing cows, drinking at will resulted in an increase in milk production of about 0.5 per cent over watering twice a day and about 1.4 per cent over watering once a day.

Summaries of the three experiments are given in Tables 8 and 9.

TABLE 8.—*Effect of frequency of watering on production of milk and butterfat, amount of water drunk, and weight of cows*

(Summary of Tables 2, 4, and 6)

Experiment No.	Watered from individual cups at will				Watered at 7 a. m. and 5 p. m.				Watered at 7 a. m.			
	Water drunk daily	Daily production		Daily gain in weight	Water drunk daily	Daily production		Daily gain in weight	Water drunk daily	Daily production		Daily gain or loss in weight
		Milk	Butterfat			Milk	Butterfat			Milk	Butterfat	
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1	63	13.9	0.58	0.19	66	13.5	0.58	0.26	60	13.7	0.57	0.35
2	49	15.4	.68	.73	46	15.4	.67	.32	42	15.2	.66	.52
3	87	31.5	1.04	.68	89	30.1	1.03	.75	76	29.6	1.00	−.03
Average	66	20.3	.77	.53	67	19.7	.76	.44	59	19.5	.74	.28

TABLE 9.—*Relative quantities of water drunk and milk produced by the cows used in the three experiments*

(Based on Tables 3, 5, and 7)

	Frequency of watering		
	From cups (at will)	Twice daily	Once daily
Water drunk	100	101	90
Milk produced	100	97	96

DISCUSSION OF RESULTS

These three experiments bring out the following facts:

When the cows (the good and the low producers considered together) were given free access to water, they produced 2.8 per cent more milk and 2.1 per cent more butterfat than when they were permitted to drink only twice a day.

When watered twice a day, they produced 1 per cent more milk and 1.4 per cent more butterfat that when watered once a day.

Cows watered twice a day drank 1.5 per cent more than when drinking at will and 13.3 per cent more than when watered once a day.

Gains in weight were about the same for cows drinking at will as for those watered twice a day; cows watered once a day gained considerably less than those watered more frequently.

The frequency of watering had little or no effect upon the percentage of butterfat in the milk.

RELATION BETWEEN YIELD OF MILK AND FREQUENCY OF REFUSING WATER

A comparison of the production of milk with the number of times the cows refused to drink is shown in Table 10 for a group of five good producers and five poor producers. The good producing cows gave an average of about 30 pounds of milk a day and the poor cows about 15 pounds. The mean air temperatures in the barn were about the same for both groups. When watered twice a day the good cows refused water 2.8 times out of a possible 60, on an average, and the poor cows 24 times. When watered once a day, the good cows refused water 0.4 times out of a possible 30, on an average, and the poor cows, 3.6 times.

TABLE 10.—*Relation between production and the number of times water was refused*

Cow No.	Watered twice daily for 30 days					Watered once daily for 30 days		
	Daily milk yield	Mean air temperature	Number of times water refused			Daily milk yield	Mean air temperature	Number of times water refused
			a. m.	p. m.	Total			
	Pounds	° *F.*				*Pounds*	° *F.*	
GOOD PRODUCERS								
242	24.0	46	1	0	1	21.4	53	1
244	28.2	48	2	0	2	26.8	46	0
201	37.7	53	2	2	4	41.5	48	1
243	25.0	53	4	2	6	25.2	48	0
228	35.8	46	0	1	1	32.9	53	0
Average	30.1	49			2.8	29.6	50	.4
LOW PRODUCERS								
33	11.6	50	25	4	29	11.7	41	8
44	13.5	41	24	10	34	11.8	55	8
50	21.6	41	15	5	20	20.8	55	1
114	15.0	50	8	6	14	15.7	41	0
212	15.5	55	16	7	23	15.8	50	1
Average	15.4	47			24	15.2	48	3.6

EFFECT OF WARM AND COLD AIR TEMPERATURES ON FREQUENCY OF REFUSING WATER AND ON QUANTITY DRUNK

A comparison of warm and cold air temperatures with the number of times cows refused to drink is shown in Table 11. The average production of the cows during the two experiments was about the same in both experiments. When the cows were watered twice daily those in the higher mean-temperature group refused water 13 times out of a possible 60, on an average; those in the lower mean-temperature group refused water 24 times. When the cows were watered once a day those in the higher mean-temperature group refused water 0.3 times out of a possible 30 times, on the average; those in the lower mean-temperature group refused water 3.6 times.

TABLE 11.—*Effect of air temperatures in barn on the number of times water was refused by two groups of cows of similar or about the same average production*

Cow No.	Watered twice daily for 30 days					Watered once daily for 30 days		
	Daily milk yield	Mean air temperature	Number of times water refused			Daily milk yield	Mean air temperature	Number of times water refused
			a. m.	p. m.	Total			
	Pounds	° *F.*				*Pounds*	° *F.*	
MODERATE TEMPERATURES								
19	11.0	55	26	0	26	13.8	68	0
34	7.1	55	24	0	24	9.7	68	2
51	14.7	68	7	0	7	18.9	78	0
100	9.5	68	20	0	20	11.4	78	0
111	14.7	78	2	0	2	9.8	55	0
204	24.3	78	1	0	1	18.7	55	0
Average	13.5	67			13	13.7	67	.3
COLD TEMPERATURES								
33	11.6	50	25	4	29	11.7	41	8
44	13.5	41	24	10	34	11.8	55	8
50	21.6	41	15	5	20	20.8	55	1
114	15.0	50	8	6	14	15.7	41	0
212	15.5	55	16	7	23	15.8	50	1
Average	15.4	47			24	15.2	48	3.6

The decided tendency of low-producing cows to drink in the evening and to refuse water in the morning, as shown in Tables 10 and 11, indicated that a demand for water usually followed the consumption of dry roughage, as the hay was fed in the afternoon before the cows were watered.

The data given in Table 12 are taken from all three of the experiments, and they show the quantity of water drunk by three groups of cows in 10-day periods of varying temperatures. Although it was necessary to select different cows for the high-temperature experiments, their live weight and milk production were approximately the same as those of the cows with which they were compared. Although the total quantity of water drunk depends on individuality to some extent, it is believed that the error from this source in the last period is not great.

TABLE 12.—*Comparison of quantities of water drunk by cows of about the same size and production, during periods of low, medium, and high atmospheric temperatures*

Period	Average daily temperature		Cow No.	Average daily production of milk	Weight of cow	Average amount water drunk daily
	Maximum	Minimum				
	°F.	°F.		Pounds	Pounds	Pounds
Jan. 4–13	44.5	32.9	212	17.8	964	61
Do	44.5	32.9	33	11.8	958	29
Do	44.5	32.9	44	13.5	828	38
Average				14.4	917	43
Mar. 15–24	63.8	52.1	212	16.5	1,011	60
Do	63.8	52.1	33	11.0	992	32
Do	63.8	52.1	44	12.2	824	37
Average				13.2	942	43
July 22–31	87.3	73.6	111	16.4	957	85
Do	87.3	73.6	100	12.5	965	72
Do	87.3	73.6	34	12.7	930	74
Average				13.9	951	77

The average daily temperature in the barn for the period March 15 to March 24 was about 20° higher than that from January 4 to January 13, but the quantity of water drunk per cow in these two periods was the same; however, in the period of higher temperatures (July 22–31), 34 pounds a day, or 79.1 per cent, more water per cow was drunk than during the interval, January 4–13.

EFFECT OF CONTINUOUS ACCESS TO WATER FOR SIX HOURS A DAY AS COMPARED WITH WATERING TWICE A DAY

On the average farm, cows can be given access to water after each feeding only by having drinking cups in the stalls or by turning the entire herd out of the barn to drink every morning and evening. Where barns are not equipped with drinking cups and the drinking troughs are outdoors, a common winter practice is to turn the herd out to drink once a day. The length of time the cows remain outdoors depends upon the weather, but whether the period be long or short, or whether the cows drink once or several times during that period, they do not have access to water after both morning and evening feedings. A short experiment was conducted to determine whether cows drink more water when permitted to drink twice a day after feeding than when given free access to water for a part of each day.

Two groups of cows were used in this experiment. One group was watered at 7 a. m. and 5 p. m. for 20 days. After 5 days this group was given access to water from 7 a. m. to 1 p. m. for 20 days. The procedure was reversed for the other group. In the beginning of the experiment there were 3 cows in each group; however, 1 cow developed a severe case of garget and had to be dropped, which left 5 cows for which the data were complete. Both groups were confined in the barn at night and turned out during the day. The same rations were fed throughout the experiment. Table 13 shows that the cows watered twice a day after feeding gave a little more milk and drank about 5 pounds, or 7.1 per cent more water, per cow per day than when access to water was given for a part of each day between feeding hours.

TABLE 13.—*Effect of watering twice a day after feeding and of six hours continuous access to water, upon quantity of water drunk, milk produced, and gain in weight*

Cow No.	Watered twice daily			Access to water 6 hours daily		
	Water drunk daily	Milk produced daily	Daily gain in live weight	Water drunk daily	Milk produced daily	Daily gain in live weight
	Period 1			Period 2		
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
67	64	19.1	2.25	65	21.8	0.97
242	74	21.0	1.77	70	19.6	1.60
243	75	21.4	1.70	81	21.0	2.00
	Period 2			Period 1		
244	87	27.6	1.00	75	27.2	1.52
246	74	17.5	2.77	61	16.3	3.42
Average	75	21.3	1.90	70	21.2	1.90

OTHER FACTORS INFLUENCING QUANTITY OF WATER DRUNK

QUANTITIES DRUNK DURING THE DAY AND AT NIGHT

As the quantity of water drunk by the cows using the drinking cups was recorded promptly at 7 a. m. and 7 p. m. each day, an opportunity was afforded for comparing the quantity drunk at night with that drunk during the day. As it was considered probable that the demand for water was was greatest immediately after eating dry hay, the hour of feeding the hay was changed from 4.30 p. m. to 7.30 p. m. for 15 consecutive days out of each 30-day period when the cows had free access to water. Hay was fed only once a day. Table 14 shows the quantity of water drunk per cow per day. During the 15 days when hay was fed at 4.30 p. m., 73.1 per cent of the water was drunk between 7 a. m. and 7 p. m. During the 15 days when hay was fed at 7.30 p. m., only 58 per cent of the water was drunk during the day. It is clear, therefore, that although feeding hay in the evening resulted in an increase in the quantity of water drunk at night, the cows always drank more water during the day, regardless of this factor.

TABLE 14.—*Comparison of quantity of water drunk by cows during the day with that drunk at night*

Cow No.	Average quantity of water drunk per day—				Cow No.	Average quantity of water drunk per day—			
	When the hay was fed at 4.30 p. m.		When the hay was fed at 7.30 p. m.			When the hay was fed at 4.30 p. m.		When the hay was fed at 7.30 p. m.	
	7 a. m. to 7 p. m.	7 p. m. to 7 a. m.	7 a. m. to 7 p. m.	7 p. m. to 7 a. m.		7 a. m. to 7 p. m.	7 p. m. to 7 a. m.	7 a. m. to 7 p. m.	7 p. m. to 7 a. m.
	Pounds	*Pounds*	*Pounds*	*Pounds*		*Pounds*	*Pounds*	*Pounds*	*Pounds*
33	31	0	21	14	201	61	33	51	36
44	40	5	30	15	242	69	25	53	25
50	45	15	34	22	243	48	36	42	38
114	32	17	20	25					
212	53	8	34	31	Average	47	17	36	26

SUCCULENCE IN THE RATION

No comparison of the quantities of water drunk when different rations are fed can be drawn from the results of these experiments, because of the similarity of the rations used throughout. However, some information is furnished by another experiment, in which a cow was given different quantities of succulent feeds. Table 15 shows how the quantity of water drunk by this cow decreased when silage in the ration was replaced by turnips. This cow was a grade weighing approximately 1,050 pounds, and the conditions under which she was kept were as far as possible the same for all periods.

TABLE 15.—*Effect of substituting turnips for silage upon quantity of water drunk by a cow*

Period	Average daily temperature in the barn		Average daily milk yield	Average quantity of water drunk daily	Average daily ration			
	Maximum	Minimum			Turnips	Silage	Grain	Clover hay
	°F.	°F.	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
Feb. 26 to Mar. 4	58.4	43.4	27.0	64.8	0	26	10	4
Mar. 21 to Mar. 27	64.2	48.2	24.5	29.8	81.7	0	10	4
Mar. 28 to Apr. 3	52.7	36.7	24.4	0	115.7	0	10	4

When 81.7 pounds of turnips replaced 26 pounds of silage in her ration the average quantity of water drunk per day declined from 64.8 to 29.8 pounds. When 115.7 pounds of turnips was consumed daily the cow refused water for seven consecutive days. Turnip feeding was then discontinued.

In order to compare the total water intake of this cow when fed either silage or turnips as the sole succulent feed, the water content of these feeds was determined. The silage contained 66.4 per cent water and the turnips, 93.8 per cent. As the hay and grain allowances remained uniform, no attention was given to the water content of these feeds. Table 16 shows the total water intake of this cow per day.

TABLE 16.—*Total daily water intake of cow when fed silage and two different quantities of turnips*

Period (7 days)	Water drunk daily	Water consumed daily in silage	Water consumed daily in turnips	Total daily intake of water
	Pounds	Pounds	Pounds	Pounds
1	64.8	17.2	----------	82.0
2	29.8	----------	76.6	106.4
3	0	----------	108.5	108.5

Experiments (7) in which the feeding value of pricklypear, a very succulent feed, and sorghum hay were compared, give further evidence tending to show that the feeding of succulent rations decreases water consumption. Three groups of three cows each were used. One group was fed sorghum hay; the second, a medium ration of pricklypear; the third, a heavy ration of pricklypear. The experiment covered a period of three days. The average daily water consumption for the three groups was 69, 30, and 5 pounds per cow, respectively.

SUMMARY

When cows were given free access to water they produced 2.8 per cent more milk and 2.1 per cent more butterfat than when they were permitted to drink twice a day.

When cows were permitted to drink twice a day they produced 1 per cent more milk and 1.4 per cent more butterfat than when permitted to drink only once a day.

Cows watered twice a day drank 1.5 per cent more than when drinking at will and 13.3 per cent more than when watered once a day.

The increase in milk production due to more frequent watering was more marked in the case of the good producers than in the case of the low producers.

Cows producing 15 pounds or more of milk per day seldom refused to drink when given access to water twice daily. Low producers refused water more frequently than did good producers.

The number of times a day that cows wanted water depended largely upon the atmospheric temperature.

Cows fed similar rations consumed 79.1 per cent more water in hot weather than in cold weather. They consumed about the same amount in moderate weather as in cold weather, but more during the day than at night.

Even low-producing cows usually wanted water after they had been fed hay.

The quantity of water drunk decreased as the quantity of succulent material in the ration was increased. The replacement of silage by turnips in the ration resulted in a greater total ingestion of water.

LITERATURE CITED

(1) ANONYMOUS.
1893. UEBER DIE WIRKUNG AUTOMATISCHER TRÄNKEN. Molk. Ztg. [Hildesheim] 7: 40.

(2) ———
1928. THE USE OF WATER-BOWLS. INFLUENCE ON MILK YIELD. Jour. Min. Agr. [Gt. Brit.] 34: 917.

(3) BACKHAUS, A.
1898. FORSCHUNG ÜBER PFLEGE UND HALTUNG DER MILCHKUH. Ber. Landw. Inst. Königs 2: 34–89.

(4) HAYWARD, H.
1901. METHODS OF DAIRY FEEDING. Penn. Agr. Expt. Sta. Bul. 56, 6 p.

(5) HILLS, J. L.
1901. WATERING COWS AT WILL AND AT INTERVALS. Vt. Agr. Expt. Sta. Ann. Rpt. (1899/1900) 13: 435–437.

(6) LARSEN, C., HUNGERFORD, E. H., and BAILEY, D. E.
1917. THE RÔLE OF WATER IN A DAIRY COW'S RATION. S. Dak. Agr. Expt. Sta. Bul. 175, p. [649] –680.

(7) WOODWARD, T. E., TURNER, W. F., and GRIFFITHS, D.
1915. PRICKLY PEARS AS A FEED FOR DAIRY COWS. Jour. Agr. Research 4: 405–470, illus.

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THE SHEDDING OF 4-LOCK AND 5-LOCK BOLLS IN UPLAND COTTON

By R. E. BECKETT, *Principal Scientific Aid*, and J. W. HUBBARD, *Senior Scientific Aid, Division of Cotton, Rubber, and Other Tropical Plants, Bureau of Plant Industry*

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INTRODUCTION

In cotton culture the loss of floral buds and young bolls by shedding is of great agricultural importance, and little is known regarding its causes or methods of control. Shedding follows the abortion or blasting of squares and young bolls, either from external injuries, as by pests and diseases, or from any physiological disturbances that may inhibit development. There is a widespread opinion among growers that shedding, when not caused by recognized pests or diseases, is a natural result of an overproduction of flowers rather than an abnormality of the plant. Another opinion is that shedding is itself a disease, for which remedies should be sought.

Eaton,[1] in some of his studies of factors associated with the shedding of floral buds and immature bolls of cotton in the Southwest, reports that "A very intimate relationship exists between the fruitfulness of the plants and the factors which influence the rate of photosynthesis." He also explains that "The nutritional relationships of the cotton plant in these regions are responsible for a considerable part of the boll shedding, which occurs every year," and that "The amount of fruit which is already carried by a cotton plant greatly influences the further growth which the plant can make, the number of flowers to appear and the number of bolls to be retained."

Data on shedding recorded at various locations in the Cotton Belt of the United States have shown wide variations in the amount

[1] EATON, F. M., DEFRUITING AS AN AID IN COTTON BREEDING. Jour. Heredity 18: 457-460, illus. 1927.

of shedding under different conditions of growth. Contrasting differences have also been observed in the amount of shedding by different kinds of cotton grown in side-by-side comparisons. Cook,[2] in discussing causes of shedding, points out that "Egyptian cotton may retain nearly all of its buds and young bolls while upland varieties in adjacent rows are shedding nearly all of their buds."

During the last few years many data on the shedding of cotton bolls have been published, but none of the reports reviewed have considered a relation between the number of locks per boll and the rate of shedding. Studies of the amount of pollen required to develop a boll and experiments with different methods of pollination, conducted by Meade,[3] indicate that some of the shedding of young bolls is due to imperfect fertilization. Since each lock in a boll is represented by a lobe of the stigma and contains ovules to be fertilized, the possibility of imperfect fertilization increases with each additional lock.

It now is indicated that types of cotton characterized by small bolls with few locks also have less tendency to shed. Most of the primitive upland types of cotton have fewer locks per boll than do the cultivated types, and the increase in the number of locks per boll in the cultivated varieties may be largely due to selection and to improved cultural conditions. Evidence has been obtained at Greenville, Tex., and at Bard, Calif., showing that 5-lock bolls may have a greater tendency to abort than have 4-lock bolls.

Selection of 5-lock bolls in the upland type of cotton has been in progress for many years, and the results obtained represent the combined efforts of many plant breeders. The efforts to establish the 5-lock boll as a constant character in the Texas big-boll varieties have been based upon the supposition that a cotton with 5-lock bolls would be more productive and would require less labor to pick, but there seems to be no scientific evidence to support the popular opinion that a variety of cotton producing 5-lock bolls exclusively would be superior in all respects to a variety with some 4-lock bolls.

Since the trend in cotton breeding is to select for 5-lock bolls, the need of more information regarding this character is obvious, and more work needs to be done to determine the feasibility of establishing such a character.

METHODS AND MATERIALS

The data presented in this bulletin were collected at the United States Cotton Breeding Field Station, Greenville, Tex., in 1925, and at the United States Acclimatization Garden, Bard, Calif., in 1926 and 1927.

The Lone Star variety was chosen for the experiments conducted at Greenville, Tex., as being typical of the Texas big-boll group of varieties. It was developed by the United States Department of Agriculture from a single plant, selected in a field of Jackson cotton in 1905, and is grown extensively in Texas and adjacent States.

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[2] COOK, O. F. CAUSES OF SHEDDING IN COTTON. Jour. Heredity 12: 199–204, illus. 1921.

[3] MEADE, R. M. BEE KEEPING MAY INCREASE THE COTTON CROP. Jour. Heredity 9: 282–285, illus. 1918.

The Acala variety was chosen for all experiments in California, since it has proved to be superior to other big-boll varieties in the irrigated valleys of the Southwest and has been adopted as the standard variety in California under the State laws of community production. This variety was introduced from Mexico by the United States Department of Agriculture in 1906.

The use of two varieties in these studies limits the comparability of the data collected, as direct comparisons can not be made in all cases. However, since the results obtained under similar conditions coincide, varietal differences that may exist are not of great importance in this discussion.

In these studies the number of locks per boll was determined during the flowering stage by counting the number of lobes of the stigma. These lobes are well defined so that the number of locks can be determined readily and accurately. Flowers with 4-lobed stigmas were recorded as 4-lock flowers, and those with 5-lobed stigmas were recorded as 5-lock flowers. The date of flowering was recorded as the initial date in the production of the boll. These records were kept on small tags placed on the pedicels of the flowers, each tag bearing the date of flowering and the number of lobes of the stigmas or locks in the boll.

Daily collections of the fallen tags from young bolls that had been shed were made, and the date of shedding was recorded. At Greenville, Tex., an examination was made of each aborted boll to determine whether the shedding was due to injury by insects or to some other external cause. This precaution was taken because of the presence of the boll weevil in Texas, and was not considered essential to the experiments conducted in California.

Additional records were kept of the number and kind of flowers tagged on each date, and of the number and kind of bolls that fell. From these records the number of 4-lock and 5-lock bolls remaining on the plants could be determined for any given date. As the bolls that developed reached maturity the tags were taken off and marked with the date of opening, each boll being examined to see that the number of locks in the boll checked with the number recorded on the tag. Then at the end of the season the bolls that reached maturity and the bolls that fell were checked against the flowers tagged, in order to guard against errors in field work.

EXPERIMENTS AT GREENVILLE, TEX.

COMPARATIVE RATE OF SHEDDING

In the first series of observations, conducted at Greenville, Tex., in 1925, five comparisons of the rate of shedding of 4-lock and 5-lock bolls were made at weekly intervals from June 30 to July 28. For each of these comparisons 100 flowers with four locks and 100 flowers with five locks were tagged, except in the last comparison, when only 50 flowers with four locks were available. The records of these comparisons in each case show a higher percentage of shedding in the 5-lock bolls than in the 4-lock bolls.

For the June 30 comparison 38 per cent of the 4-lock bolls fell, as compared with 46 per cent of the 5-lock bolls, and for July 7 comparison 48 per cent of the 4-lock bolls fell, as compared with 56

per cent of the 5-lock bolls. As the season advanced, the amount of shedding of both 4-lock and 5-lock bolls increased greatly, but a slightly higher percentage of 5-lock bolls continued to be shed throughout the period in which data were recorded. For the comparisons of July 14, 21, and 28, the rate of shedding of 4-lock bolls was 80, 95, and 90 per cent, respectively, as compared with 84, 96, and 95 per cent of the 5-lock bolls. The high rate of late-season shedding greatly reduced the apparent differences in the rate of shedding of the 4-lock and 5-lock bolls, expressed in percentages of the total.

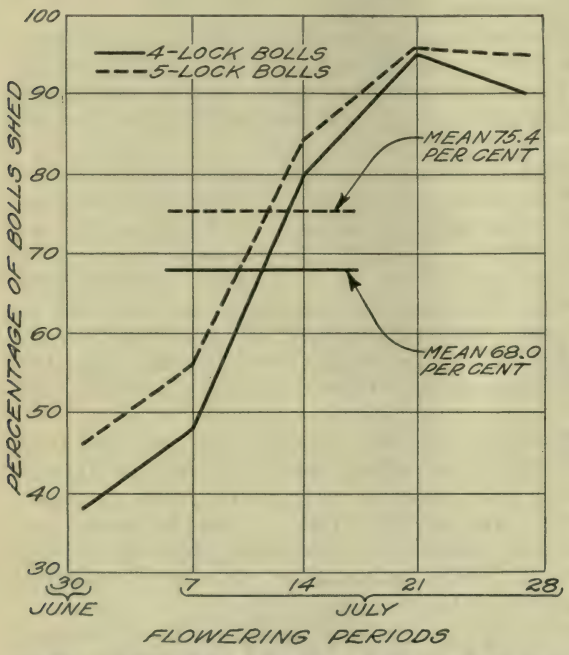

FIGURE 1.—Percentages of 4-lock and 5-lock bolls shed from flowers opened June 30 and July 7, 14, 21, and 28, 1925, on Lone Star cotton at Greenville, Tex.

Of a total of 450 flowers with four locks that were tagged, 144 bolls, or 32 per cent, reached maturity, whereas of 500 bolls with five locks, only 123 bolls, or 24.6 per cent, matured. These differences, though small, are in favor of the 4-lock boll in each comparison, and during the early flowering period, when the rate of shedding was not so great, significant differences are shown. The date and number of flowers tagged for each comparison, the number of 4-lock and 5-lock bolls shed, and the total number and percentages of 4-lock and 5-lock bolls shed are shown in Table 1. The percentages of 4-lock and 5-lock bolls shed for each date are shown graphically in Figure 1.

TABLE 1.—*Flowers tagged each week from June 30 to July 28 and bolls shed from each group of 4-lock and 5-lock bolls on Lone Star cotton at Greenville, Tex., 1925 percentages of totals*

Date	4-lock—		5-lock—	
	Flowers tagged	Bolls shed	Flowers tagged	Bolls shed
	Number	*Number*	*Number*	*Number*
June 30	100	38	100	46
July 7	100	48	100	56
14	100	80	100	84
21	100	95	100	96
28	50	45	100	95
Total	450	306	500	377
Per cent	----------	68	----------	75

EARLY AND LATE FLOWERING PERIODS

In the second series of observations conducted at Greenville, Tex., in 1925, a complete record was kept of the flowers produced and the bolls aborted on 25 consecutive plants selected from each of four adjacent rows. These plants produced flowers in two distinct periods—an early flowering period from July 4 to August 14, and a late flowering period from September 17 to October 21. This break in the flowering period is of common occurrence in many regions, the late-season bolls usually being referred to as the top crop.

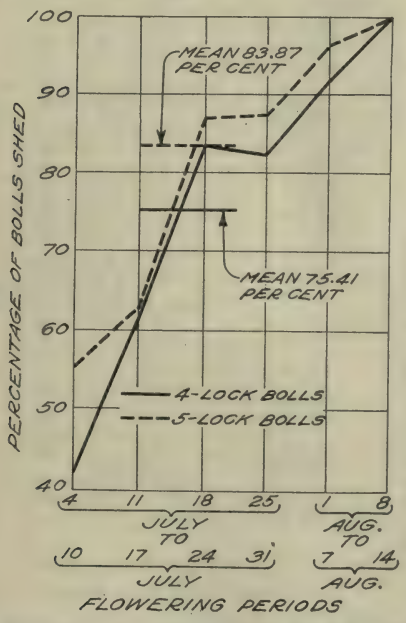

FIGURE 2.—Percentages of 4-lock and 5-lock bolls shed from flowers produced on 100 plants of Lone Star cotton at Greenville, Tex., from July 4 to August 14, 1925

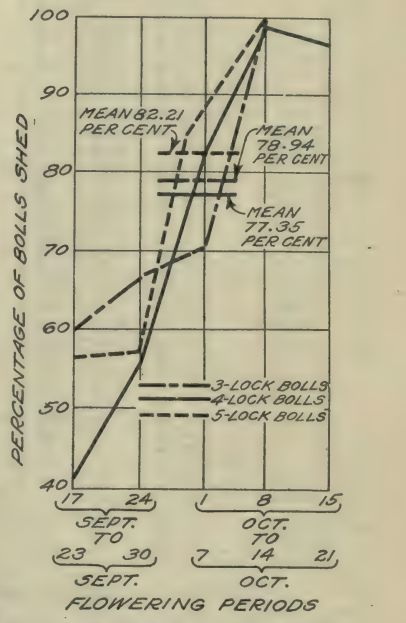

FIGURE 3.—Percentages of 3-lock, 4-lock, and 5-lock bolls shed from flowers produced on 100 plants of Lone Star cotton at Greenville, Tex., from September 17 to October 21, 1925

The numbers of 4-lock and 5-lock flowers produced on the 100 plants each day during the first flowering period, from July 4 to August 14, and the numbers of bolls subsequently shed are shown in Table 2. Totals of the 4-lock flowers produced and the bolls shed are given by weeks, with percentages of shedding. Similar data obtained during the second or late flowering period are presented in Table 3. The rate of shedding of 4-lock and 5-lock bolls during the early and late flowering periods are shown graphically in Figures 2 and 3. The abrupt termination of the second flowering period, as shown in Table 3, was due to an invasion of army worms which defoliated the plants and destroyed the floral buds.

TABLE 2.—*Four-lock and five-lock flowers produced and young bolls shed on 100 plants of Lone Star cotton at Greenville, Tex., July 4 to August 14, 1925*

Date	4-lock—		5-lock—	
	Flowers produced	Bolls shed	Flowers produced	Bolls shed
	Number	*Number*	*Number*	*Number*
July 4	7	4	2	0
5	9	3	6	0
6	6	1	13	7
7	2	0	4	1
8	18	8	19	12
9	15	8	8	6
10	16	7	18	13
Total	73	31	70	39
Per cent	------	42.46	------	55.71
July 11	29	17	20	10
12	21	10	22	8
13	36	22	35	17
14	17	12	29	19
15	18	6	26	16
16	24	18	53	33
17	25	19	41	38
Total	170	104	226	141
Per cent	------	61.18	------	62.39
July 18	18	12	71	57
19	47	31	113	87
20	31	25	83	64
21	32	[1] 24	92	[2] 81
22	65	60	126	118
23	51	50	108	101
24	38	34	97	93
Total	282	236	690	601
Per cent	------	83.69	------	87.10
July 25	33	32	79	71
26	45	36	131	110
July 27	50	43	145	125
28	43	26	105	78
29	27	25	115	111
30	17	15	74	72
31	5	4	44	40
Total	220	181	693	607
Per cent	------	82.27	------	87.59
Aug. 1	8	6	31	30
2	6	5	42	39
3	7	6	17	17
4	6	6	19	18
5	6	6	12	12
6	9	9	7	7
7	8	8	5	5
Total	50	46	133	128
Per cent	------	92.00	------	96.24
Aug. 8	3	3	8	8
9	3	3	9	9
10	0	0	4	4
11	0	0	0	0
12	0	0	2	2
13	0	0	0	0
14	0	0	0	0
Total	6	6	23	23
Per cent	------	100	------	100
Grand total	801	604	1,835	1,539
Per cent	------	75.41	------	83.87

[1] 2 bolls shed from traumatic causes.

[2] Boll shed from traumatic causes.

TABLE 3.—*Three-lock, four-lock, and five-lock flowers produced and young bolls shed on 100 plants of Lone Star cotton at Greenville, Tex., September 17 to October 21, 1925*

Date	3-lock—		4-lock—		5-lock—	
	Flowers produced	Bolls shed	Flowers produced	Bolls shed	Flowers produced	Bolls shed
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Sept. 17	0	0	6	0	0	0
18	0	0	5	2	0	0
19	2	1	2	0	2	0
20	0	0	3	2	2	1
21	1	0	7	3	3	1
22	1	1	20	11	4	4
23	1	1	10	4	5	3
Total	5	3	53	22	16	9
Per cent	----------	60.00	----------	41.51	----------	56.25
Sept. 24	1	1	13	5	6	5
25	0	0	18	10	8	3
26	0	0	6	4	6	2
27	0	0	6	2	3	2
28	0	0	14	6	6	6
29	1	0	14	9	2	1
30	1	1	14	11	4	1
Total	3	2	85	47	35	20
Per cent	----------	66.66	----------	55.29	----------	57.14

TABLE 3.—*Three-lock, four-lock, and five-lock flowers produced and young bolls shed on 100 plants of Lone Star cotton at Greenville, Tex., etc.*—Continued

Date	3-lock—		4-lock—		5-lock—	
	Flowers produced	Bolls shed	Flowers produced	Bolls shed	Flowers produced	Bolls shed
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Oct. 1	1	1	13	6	4	3
2	2	1	26	19	1	1
3	2	2	29	25	7	5
4	4	2	37	34	9	10
5	5	3	32	24	11	8
6	2	2	30	26	10	8
7	1	1	28	26	7	7
Total	17	12	195	160	49	42
Per cent		70.59		82.05		85.71
Oct. 8	1	1	17	17	7	7
9	2	2	11	11	5	5
10	0	0	11	11	6	6
11	0	0	12	12	3	3
12	5	5	19	19	12	12
13	0	0	12	12	2	2
14	2	2	21	20	5	5
Total	10	10	103	102	40	40
Per cent		100.00		99.03		100.00
Oct. 15	1	1	11	11	6	6
16	1	1	4	3	2	2
17	0	0	3	3	5	5
18	0	0	2	2	2	2
19	1	1	0	0	3	3
20	0	0	3	3	1	1
21	0	0	9	9	4	4
Total	3	3	32	31	23	23
Per cent		100.00		96.88		100.00
Grand total	38	30	468	362	163	134
Per cent		78.95		77.35		82.21

During the early flowering period the 100 plants selected produced 1,835 flowers with 5 locks and 801 flowers with 4 locks. No 3-lock flowers were produced during that period. During the later flowering period these plants produced 163 flowers with 5 locks, 468 flowers with 4 locks, and 38 flowers with 3 locks. These figures indicate decided seasonal effects upon the relative production of 3-lock, 4-lock, and 5-lock bolls.

The percentage of the young bolls that were shed increased gradually from the first week of the early flowering period, ended July 10, when 42.47 per cent of the 4-lock bolls and 55.71 per cent of the 5-lock bolls were shed, to the last week of the early flowering period, ended August 14, when 100 per cent of both the 4-lock and the 5-lock bolls were shed. The later flowering period, beginning September 17, shows a shedding rate accelerating as did that of the early period, increasing from 41.51 per cent of the 4-lock bolls and 56.25 per cent of the 5-lock bolls for the week ended September 23, to 99.03 per cent of the 4-lock bolls and 100 per cent of the 5-lock bolls for the week ended October 14. The low shedding rate at the beginning of each flowering period and the increase in the rate of shedding through both flowering periods seem to indicate a very close relationship between the rate of shedding and the number of immature bolls being carried by the plants. Most of the bolls of the first flowering period were fully matured at the beginning of the second flowering period.

The percentage of shedding of the 5-lock bolls was greater than that of the 4-lock bolls in each of the weekly intervals through both flowering periods, except in the week ended August 14, when all the bolls of each type were shed. Of a total of 801 flowers with 4 locks produced during the early flowering period, 197 bolls, or 24.59 per cent, reached maturity, whereas of a total of 1,835 flowers with 5 locks only 296 bolls, or 16.13 per cent, matured.

During the late flowering period a large percentage of the bolls had 4 locks and some 3 locks, but the relations between the rates of shedding of 4-lock and 5-lock bolls remained practically the same. Of a total of 163 flowers with 5 locks produced during the late flowering period, 29 bolls, or 17.79 per cent, reached maturity, as compared with 468 flowers with 4 locks, of which 106 bolls, or 22.65 per cent, reached maturity, and with 38 flowers with 3 locks, of which 8 bolls, or 21.05 per cent, matured.

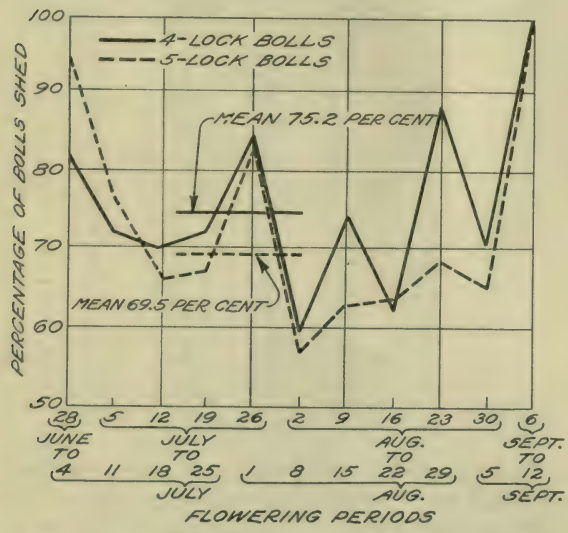

FIGURE 4.—Percentages of 4-lock and 5-lock bolls shed by 25 plants of Acala cotton grown at Bard, Calif., shown in weekly periods from June 28 to September 12, 1926, with mean percentages of bolls shed for the entire period

Of a grand total of 1,269 flowers with 4 locks, 303 bolls, or 23.88 per cent, reached maturity, as compared with a grand total of 1,998 flowers with 5 locks, of which 325 bolls, or 16.27 per cent, reached maturity.

The question still remains as to whether the increase in percentage of 4-lock bolls matured over the percentage of 5-lock bolls matured is due to a greater persistence of the 4-lock bolls, and whether the plants would be able to mature a greater quantity of seed cotton if only flowers with 4 locks were produced. As indicated by the percentages of bolls that matured, if all the flowers produced on the 100 plants had been 4-locked, the quantity of seed cotton would have been greater than if all the flowers produced had been 5-locked. Disregarding the 3-lock bolls, a crop of 780 4-lock bolls would have been matured, as against 531 5-lock bolls. Considering these 531 5-lock bolls as equivalent to 664 4-lock bolls, there is a difference of 116 4-lock bolls.

EXPERIMENTS AT BARD, CALIF.

RESULTS UNDER USUAL IRRIGATION AND CULTURAL METHODS

Records of the number of 4-lock and 5-lock flowers produced and of the percentages of bolls shed were kept on each of 25 plants grown at Bard, Calif., in 1926. These plants were selected in a field of

Acala cotton grown under irrigation according to the customary cultural methods employed at Bard. The individual records of these plants are arranged in Table 4 in the order in which the plants stood in the row. These records show a wide variation in the production and rate of shedding of both 4-lock and 5-lock bolls. The mean weekly percentages of 4-lock and 5-lock bolls shed by the 25 plants are shown in Figure 4.

TABLE 4.—*Individual records of 25 plants of Acala cotton grown at Bard, Calif., in 1926, showing number of flowers produced, percentage of bolls with 5 locks, and percentage of 4-lock and 5-lock bolls shed*

Plant No.	Flowers produced	Bolls with 5 locks	4-lock bolls shed	5-lock bolls shed	Plant No.	Flowers produced	Bolls with 5 locks	4-lock bolls shed	5-lock bolls shed
	Number	*Per cent*	*Per cent*	*Per cent*		*Number*	*Per cent*	*Per cent*	*Per cent*
1	128	67.2	64.3	66.3	15	73	75.1	88.9	65.5
2	82	67.1	81.5	63.5	16	76	67.0	80.0	58.9
3	61	72.1	64.7	58.5	17	120	54.1	78.3	70.8
4	90	77.8	60.0	64.3	18	99	68.7	91.1	72.0
5	40	67.5	66.9	55.5	19	61	74.8	81.2	68.9
6	56	73.2	66.6	75.6	20	55	69.1	76.4	60.5
7	137	77.4	67.7	52.9	21	89	74.2	74.9	79.2
8	135	64.5	50.0	69.0	22	99	79.8	75.0	62.1
9	56	93.7	75.0	64.0	23	82	83.4	50.0	72.3
10	102	66.7	82.4	60.3	24	94	70.2	71.3	60.7
11	110	62.7	68.3	68.1	25	67	64.1	75.0	55.3
12	145	68.9	71.1	62.0					
13	148	78.4	81.3	62.1	Total	2,293	70.6	75.2	69.5
14	88	59.1	77.7	65.4					

The total number of flowers produced per plant ranged from 40 for plant No. 5 to 148 for plant No. 13, with a mean of 91.72 flowers per plant. Of all the flowers produced, 70.6 per cent became 5-lock bolls. The percentage of flowers developing into 5-lock bolls ranged from 54.1 per cent on plant No. 17 to 93.7 per cent for plant No. 9.

Of the total number of 5-lock bolls produced, 69.5 per cent were shed. On individual plants percentages of 5-lock bolls that were shed ranged from 52.9 per cent for plant No. 7 to 79.2 per cent for plant No. 21.

Of all the 4-lock bolls produced, 75.2 per cent were shed. Individual plants shed from 50 per cent of their 4-lock bolls, as for plants Nos. 8 and 23, to 91.1 per cent for plant No. 18.

For 19 of the 25 plants in this series the percentage of 4-lock bolls shed was greater than the percentage of 5-lock bolls shed, and the mean percentage of 4-lock bolls shed was 5.7 per cent greater than that of the 5-lock bolls.

Although the differences were small between the rate of shedding of 4-lock and 5-lock bolls, the general trend was toward a higher shedding rate of 4-lock bolls and at variance with the results obtained in the previous studies.

Since this series of observations was conducted under widely different environmental and cultural conditions from those at Greenville, Tex., the results are not comparable. However, these differences have made it possible to study from various angles the number of locks per boll as a plant character, and to suggest probable causes of the higher rates of shedding of the 5-lock bolls as observed at Greenville, Tex., in 1925.

EFFECTS OF VARIED CONDITIONS OF IRRIGATION, POLLINATION, AND HANDLING

The next experiment, for reasons that had suggested themselves in the course of the previous studies, was projected upon somewhat different lines. Three series of observations were made, each including two groups of plants under contrasting conditions.

A plot of Acala cotton was planted at the United States Acclimatization Garden at Bard, Calif., and special arrangements were made to give contrasting irrigation treatments. The cotton was planted April 12, following irrigation of the land on April 9. The seedlings were thinned June 1 to approximately 1 foot apart in the rows. On June 2 the plot was divided into two equal sections by a high border running parallel with the rows. One side of the border was then designated the wet section and the other the dry section. The wet section was irrigated at 2-week intervals from June 2 to August 23 and again on October 19, while the dry section was irrigated only three times during the season—July 26, August 23, and October 19.

On June 24 the first series of observations was begun. Fifteen consecutive plants were selected from each section in order to compare the production and shedding of 4-lock and 5-lock bolls under normal and under stress conditions. All the flowers produced on these 30 plants were labeled with tags bearing the date of flowering and the number of stigma lobes, or locks per boll. The tags from shed bolls and from mature open bolls were collected and dated as in the previous studies. This study was designated the open-pollinated series, the flowers being left open to be pollinated by insects, as in previous studies.

For comparison with the foregoing series, 15 consecutive plants in rows adjacent to the open-pollinated plants were selected from each section. The flowers were self-pollinated, that is, each flower was kept closed to prevent the entrance of insects by placing a small rubber band over the tip of the corolla just before it began to open. Since the flowers of this series were not allowed to open, the number of locks could not be determined during anthesis but was recorded when the tags of the shed bolls and the mature open bolls were collected. These plants were designated the self-pollinated series.

On July 15 another series of observations was begun on 15 consecutive plants in each section, selected in rows adjacent to the open-pollinated series. These plants were treated in the same manner as those of the open-pollinated series, except that each flower was pollinated by hand, with pollen from another plant. The pollinating was done as soon as the anthers were well open, usually between 8 and 9 a. m. These plants were designated the hand-pollinated series.

The open-pollinated series was intended primarily as a basis for a study of the effects of stress conditions upon the production and the rate of shedding of 4-lock and 5-lock bolls. It also served as a check for the self-pollinated and hand-pollinated series, which were devised to study the effects of pollination upon the rate of shedding of 4-lock and 5-lock bolls. In comparing the wet and dry sections, consideration must be given to the fact that while fewer flowers were produced on the dry sections, higher percentages of the bolls were retained. On account of the abundance of bees, wasps, and other pollinating insects, little difference could be expected between

the results in the open-pollinated and hand-pollinated series. In one case it was certain that foreign pollen was introduced on to the stigma of each flower, and in the other case it was highly probable.

The different methods of pollination gave no apparent effects in these studies. At least no significant differences are traceable to this cause. However, the conditions existing at Bard, Calif., were unfa-

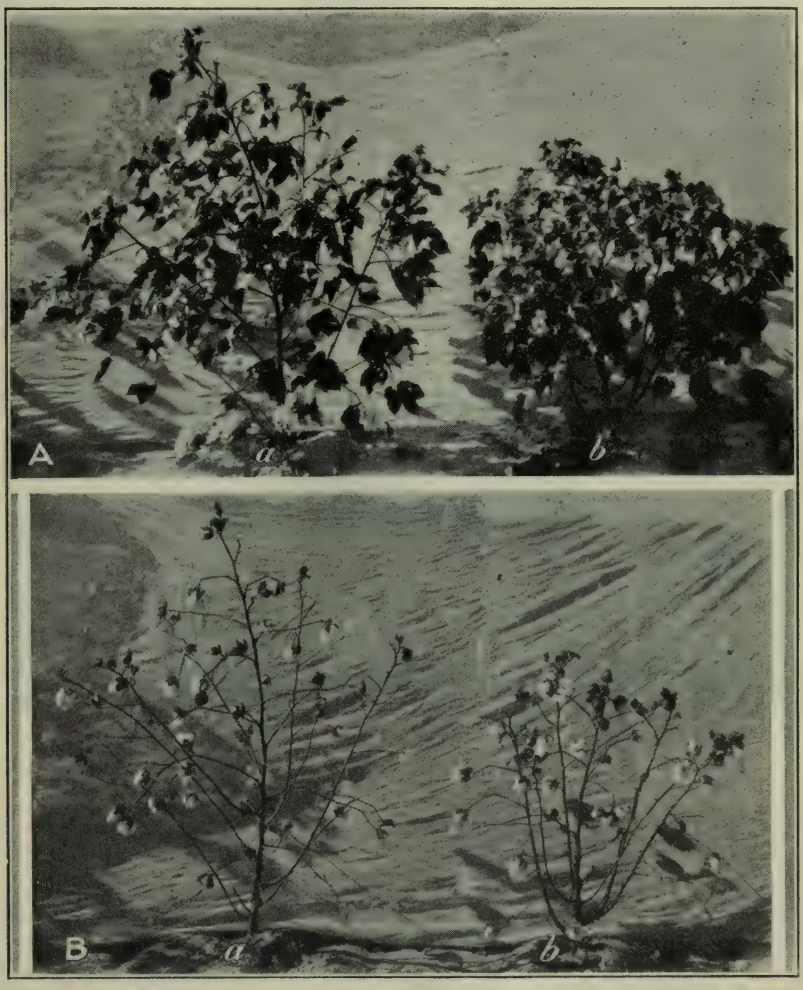

FIGURE 5.—Effect of excessive handling on development of cotton plants: A, Plants in the wet section of the self-pollination series; *a*, normal plant; *b*, excessively handled plant in an adjacent row, showing more compact and rigid structure; B, same plants defoliated to show development of stalks and branches. Note the sturdy upright habit of the much-handled plant (*b*)

vorable for these studies because of the abundance of pollinating insects, and no conclusions can be drawn from the results obtained.

The comparability of the self-pollinated series is somewhat impaired by the striking effects of the handling of plants upon their habits of growth and physical development. (Figs. 5 and 6.) The effects of handling upon the open-pollinated and the hand-polli-

nated series were only slightly noticeable in comparison with plants in adjoining rows that were unmolested; but in the self-pollinated series, where more than double the amount of handling of the plants was required, the effect upon development was outstanding. The additional handling of the plants in the self-pollinated series was necessary because of the extra work of self-pollinating. This work was done between 4 and 6 a. m., before the flowers opened, and much bending and twisting of the stalks and branches was necessary in order to locate all of the buds that were ready to bloom. The plants receiving this treatment developed into compact, rigid structures, apparently in an effort to resist the bending and twisting to which they were subjected.

In addition to being more compact and rigid in structure, the excessively handled plants were observed to be exceedingly drought resistant. This difference in the habit of growth was very pronounced

FIGURE 6.—Comparison of excessively handled (A) and normal (B) cotton plants in the same row, in the wet section of the self-pollinated series. Note the compact form of the much-handled plants and the more open development of normal plants

and rendered it impracticable to reduce the plants of the self-pollinated series to a condition of stress by withholding water without running the risk of injuring the plants of the other series in adjacent rows. The foliage of the short, bushy plants of the self-pollinated series, crowded together, remained turgid throughout the season, while the leaves of adjoining plants often were distinctly wilted. This observation is made because it appears to have a direct bearing upon the data reported, though no explanation of the effects produced by the experimental manipulation is suggested.

The effects of stress conditions of water shortage upon the number of locks per boll were apparent in the open-pollinated and hand-pollinated plants. In the open-pollinated series 76.8 per cent of the bolls produced in the wet section had 5 locks, as compared with 70.7 per cent in the dry section, while in the hand-pollinated series 74.3 per cent of the bolls produced in the wet section had 5 locks as compared with 67.4 per cent in the dry section. In the self-pollinated

series, however, this tendency was reversed, the wet section producing 72.2 per cent of 5-lock bolls, and the dry section 77.0 per cent. This difference in the production of 5-lock bolls may be associated with the difference in growth and behavior of the much-handled plants and their obviously greater resistance to the drought conditions.

Differences in the rate of shedding of 4-lock and 5-lock bolls occurred in the wet and in the dry sections of the open-pollinated and

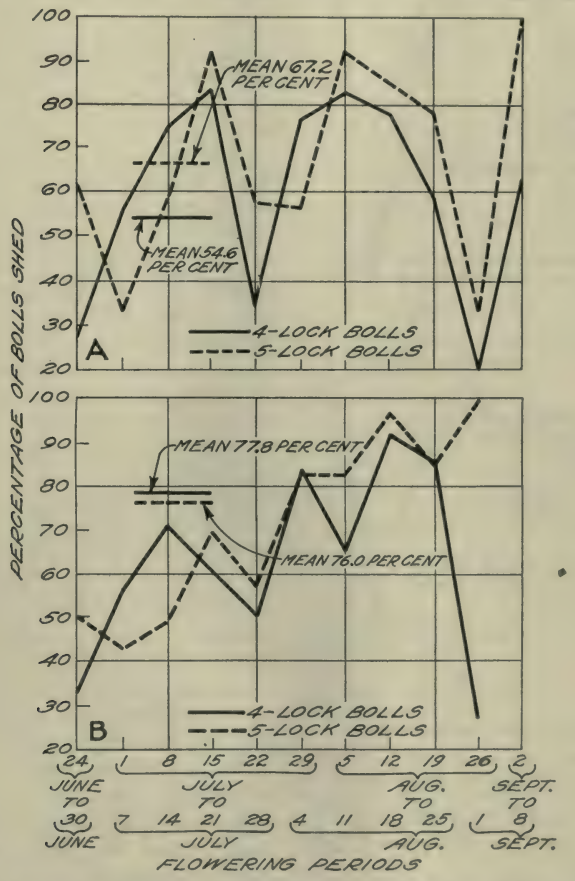
PERCENTAGE OF BOLLS SHED
MEAN 67.2 PER CENT
MEAN 54.6 PER CENT
4-LOCK BOLLS
5-LOCK BOLLS
A
MEAN 77.8 PER CENT
MEAN 76.0 PER CENT
4-LOCK BOLLS
5-LOCK BOLLS
B
24 1 8 15 22 29 5 12 19 26 2
JUNE TO JULY TO AUG. TO SEPT. TO
30 7 14 21 28 4 11 18 25 1 8
JUNE JULY AUG. SEPT.
FLOWERING PERIODS

FIGURE 7.—Percentages of 4-lock and 5-lock bolls shed from flowers produced on 30 plants of Acala cotton in the dry (A) and wet (B) sections of the open-pollinated series during consecutive 7-day periods from June 24 to September 8, 1927, at Bard, Calif.

hand-pollinated series. In the wet section the shedding of 4-lock bolls was 1.8 per cent greater in the open-pollinated plants and 2.2 per cent greater in the hand-pollinated plants than the shedding of 5-lock bolls. These results coincide with those at Bard, Calif., in 1926; whereas in the dry section the shedding of 4-lock bolls was 12.6 per cent less than the shedding of 5-lock bolls in the open-pollinated plants and 24.1 per cent less in the hand-pollinated plants. Similar results were obtained at Greenville, Tex., in 1925.

In both sections of the self-pollinated series the percentage of shedding of 5-lock bolls was greater than that of the 4-lock bolls. In the wet section 73.7 per cent of the 4-lock bolls were shed, as compared with 82.8 per cent of the 5-lock bolls; and in the dry section 55.6 per cent of the 4-lock bolls were shed, as compared with 75.3 per cent of the 5-lock bolls. The more extensive shedding of the 5-lock bolls in the self-pollinated series may be partly due to imperfect fertilization.

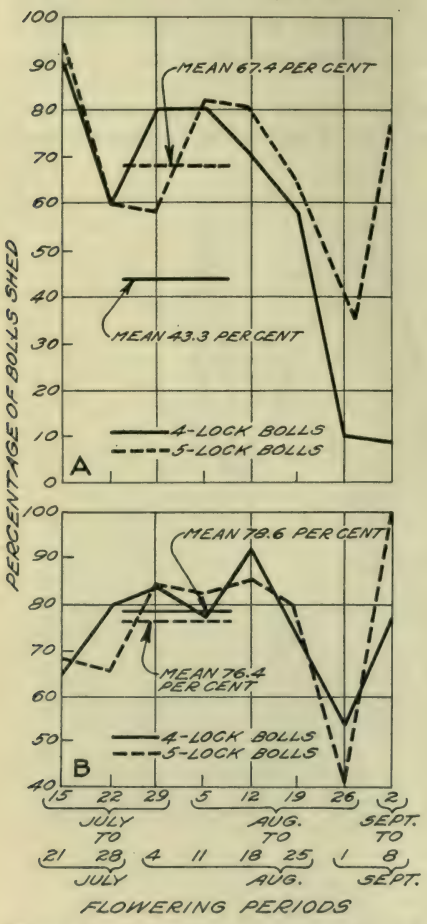

FIGURE 8.—Percentages of 4-lock and 5-lock bolls shed from flowers produced on 30 plants of Acala cotton in the dry (A) and wet (B) sections of the hand-pollinated series during consecutive 7-day periods from July 15 to September 8, 1927, at Bard, Calif.

The number of 4-lock and 5-lock flowers produced and the number and percentage of bolls shed in 7-day periods for the open-pollinated, hand-pollinated, and self-pollinated series are shown in Table 5. Also, the percentages of 4-lock and 5-lock bolls shed are shown in Figures 7, 8, and 9, representing the open-pollinated, hand-pollinated, and self-pollinated series, respectively.

The percentages of 4-lock and 5-lock bolls shed (figs. 7, 8, and 9) follow the same general trend in each series, but show differences between the wet and dry sections, due to the different methods of irrigation. Also, contrasting differences are apparent in comparing the graphs representing shedding under dry-land culture in Texas with those representing shedding under irrigation in California. Under the dry-land cultural conditions (figs. 1, 2, and 3) a gradual increase is shown in the rate of shedding throughout each flowering period. This regular behavior is in contrast to the variable shedding shown in Figures 6, 7, 8, and 9 where definite changes in rates of shedding are recorded with each irrigation.

TABLE 5.—*Four-lock and five-lock flowers produced and young bolls shed on 30 Acala cotton plants each in the wet and dry sections of the open-pollinated, hand-pollinated, and self-pollinated series for consecutive 7-day periods at Bard, Calif., 1927*

OPEN POLLINATED

Flowering period	Wet section						Dry section					
	4-lock—			5-lock—			4-lock—			5-lock—		
	Flowers produced	Bolls shed		Flowers produced	Bolls shed		Flowers produced	Bolls shed		Flowers produced	Bolls shed	
	Number	*Number*	*Per cent*	*Number*	*Number*	*Per cent*	*Number*	*Number*	*Per cent*	*Number*	*Number*	*Per cent*
June 24–30	3	1	33.3	2	1	50.0	7	2	28.6	8	5	62.5
July 1–7	9	5	55.6	14	6	42.9	16	9	56.3	23	8	34.8
July 8–14	10	7	70.0	50	24	48.0	8	6	75.0	75	44	58.7
July 15–21	5	3	60.0	74	51	68.9	6	5	83.3	108	99	91.7
July 22–28	8	4	50.0	223	126	56.5	14	5	35.7	157	91	58.0
July 29 to Aug. 4	67	56	83.6	257	212	82.5	13	10	76.9	55	31	56.4
Aug. 5–11	62	40	64.5	247	203	82.2	6	5	83.3	13	12	92.3
Aug. 12–18	87	80	92.0	142	136	95.8	14	11	78.6	20	17	85.0
Aug. 19–25	67	57	85.1	76	64	84.2	111	65	58.6	82	64	78.0
Aug. 26 to Sept. 1	11	3	27.3	5	5	100.0	35	7	20.0	27	9	33.3
Sept. 2–8	0	0	0	0	0	0	8	5	62.5	5	5	100.0
Total	329	256	77.8	1,090	828	76.0	238	130	54.6	573	385	67.2

HAND POLLINATED

July 15–21	11	7	63.6	95	63	66.3	9	8	88.9	109	101	92.7
July 22–28	14	11	78.6	220	143	65.0	10	6	60.0	146	85	58.2
July 29 to Aug. 4	56	46	82.1	230	192	83.5	20	16	80.0	54	31	57.4
Aug. 5–11	67	51	76.1	236	193	81.8	5	4	80.0	11	9	81.8
Aug. 12–18	101	94	93.1	165	140	84.8	10	7	70.0	15	12	80.0
Aug. 19–25	97	70	72.2	112	87	77.7	83	48	57.8	54	34	63.0
Aug. 26 to Sept. 1	28	15	53.6	31	13	41.9	50	5	10.0	40	14	35.0
Sept. 2–8	4	3	75.0	2	2	100.0	37	3	8.1	34	26	76.5
Total	378	297	78.6	1,091	833	76.4	224	97	43.3	463	312	67.4

SELF POLLINATED

June 24–30	5	4	80.0	10	4	40.0	1	1	100.0	3	1	33.3
July 1–7	9	8	88.9	17	17	100.0	2	1	50.0	11	6	54.5
July 8–14	23	19	82.6	82	80	97.6	7	6	85.7	62	59	95.2
July 15–21	12	10	83.3	116	106	93.4	7	5	71.4	128	107	83.6
July 22–28	12	8	66.7	238	202	84.9	16	7	43.8	260	168	64.6
July 29 to Aug. 4	62	45	72.6	263	237	90.1	46	34	73.9	200	155	77.5
Aug. 5–11	73	46	63.0	236	158	66.9	20	15	75.0	61	54	88.5
Aug. 12–18	121	109	90.1	175	156	89.1	14	13	92.9	20	20	100.0
Aug. 19–25	138	93	67.4	86	61	70.9	82	39	47.6	52	37	71.2
Aug. 26 to Sept. 1	24	10	41.7	24	11	45.8	37	12	32.4	8	1	12.5
Sept. 2–8	3	3	100.0	3	3	100.0	11	2	18.2	10	6	60.0
Total	482	355	73.7	1,250	1,035	82.8	243	135	55.6	815	614	75.3

SUMMARY

Data collected at Greenville, Tex., in 1925, and at Bard, Calif., in 1926 and 1927, indicate that 5-lock bolls may have a greater tendency to abort than 4-lock bolls. Also, 5-lock bolls are shown to be influenced by environmental and cultural conditions to a greater extent both in the number produced and in the rate of shedding, than are 4-lock bolls.

More favorable conditions tend to a lower rate of shedding of 5-lock bolls than of 4-lock bolls, as was shown in experiments conducted with Acala cotton under good conditions at Bard, Calif. These results contrast with those obtained with Lone Star cotton under less favorable conditions at Greenville, Tex., and with the Acala variety under artificial stress conditions at Bard, Calif.

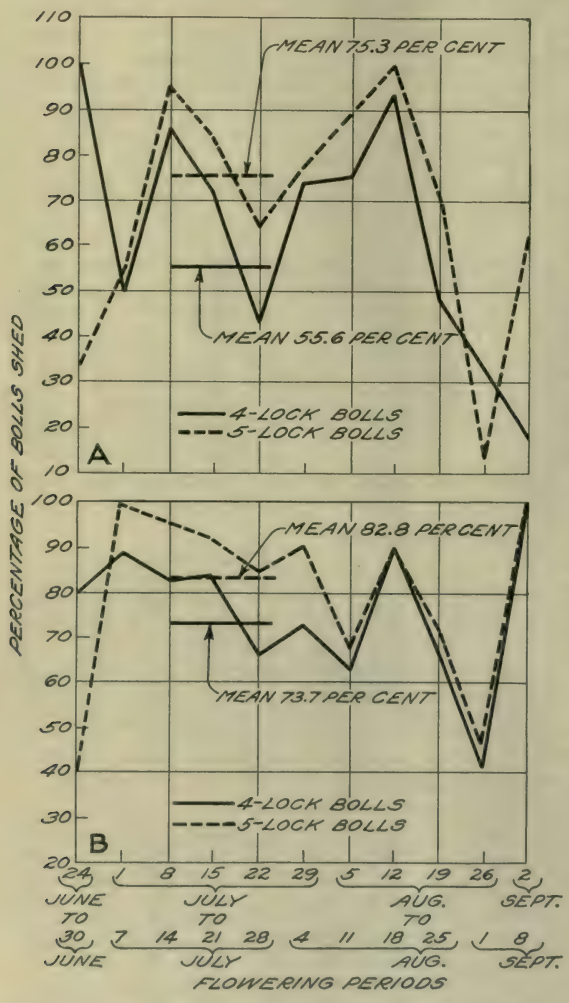

FIGURE 9.—Percentages of 4-lock and 5-lock bolls shed from flowers produced on 30 plants of Acala cotton in the dry (A) and wet (B) sections of the self-pollinated series during consecutive 7-day periods from June 24 to September 8, 1927, at Bard, Calif.

Under the dry-land cultural conditions at Greenville, Tex., the percentage of 5-lock bolls that aborted was consistently higher than that of the 4-lock bolls, whereas at Bard, Calif., under more favorable conditions of irrigation, the percentage of the 5-lock bolls that aborted was less than that of the 4-lock bolls, except in cases where the plants suffered for lack of water, or otherwise developed abnormally.

In each case at Bard, Calif., where the plants suffered for lack of water, a higher percentage of the 5-lock bolls than of the 4-lock bolls aborted. Also, a smaller percentage of the bolls were 5-locked in each case under the stress conditions. These data coincide with those collected under dry-land culture at Greenville and show that a lower percentage of 5-lock bolls are produced and a higher percentage of 5-lock bolls are shed when adverse conditions are encountered.

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THE FRACTIONATION OF AMERICAN GUM SPIRITS OF TURPENTINE AND EVALUATION OF ITS PINENE CONTENT BY OPTICAL MEANS

By S. PALKIN

Senior Chemist, Industrial Farm Products Division, Chemical and Technological Research, Bureau of Chemistry and Soils[1]

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INTRODUCTION

American gum spirits of turpentine, which is obtained almost entirely from the species *Pinus palustris* (longleaf) and *P. caribaea* (slash pine) (*22*),[2] like that from the French *P. maritima* is composed very largely of the two isomers α-pinene and nopinene or β-pinene (*12, p. 128; 14*). The quantity and proportion of these components are of considerable industrial importance in the synthesis of camphor and to some extent in the manufacture of terpin hydrate and α-terpineol (*8, 9, 10, 11*).

The gradual transition in the southeastern pine belt from the old stands of longleaf to the new growth of slash pine has raised the question as to the possible effect of this on the fundamental character of American turpentine, some influence having already been noted in the increasingly negative rotation.

Examination of turpentine from slash and longleaf pine (one sample of each) by Dupont and Barraud (*14*) showed that turpentine from the two sources varies considerably in the proportions of the two isomeric terpenes. Although the authors do not attach any importance to this difference, yet if it is found to hold consistently and if the pronounced decrease in β-pinene content is indicative of a definite change in composition, a change due to the transition, these facts would be of significance in view of the superior reactivity of β-pinene (*10, 11*) over α-pinene, especially in certain processes (*1, 3*) for synthetic camphor.

[1] Drawings of the apparatus were made by R. M. Baker, of the Chemical Engineering Division.

[2] Italic numbers in parentheses refer to Literature Cited, p. 12.

76530°—32

The object of the investigation reported in this bulletin was to examine the available means for obtaining fundamental quantitative data on the composition, particularly the major components, of the predominant American gum spirits of turpentine and to obtain data on the composition of turpentines from the well-known sources.

METHODS OF SEPARATING α AND β PINENE

With the possible exception of ozonization (*4*, *13*), no chemical methods for differentiating the two isomers α and β pinene have been found to be quantitative. The well-known classic reactions, for example, oxidation to pinonic and nopinic acids respectively, are productive of low yields and are unsuitable even for approximately quantitative purposes.

Complete quantitative separation of the two from one another and from the tailings by fractional distillation or other physical means, although theoretically possible, would in view of the similarity of physical properties be impracticable.

Darmois (*9*, *10*) has shown that by means of an effective fractionating column French gum spirits (also American) is resolved, with the exception of a very small quantity at the beginning ("head") and end ("tailings") of the distillation, into the isomers α and β pinene, and mixtures of the two in varying proportions, and that their respective proportions can then be ascertained by the Biot relationship (*12*, *p. 98*). By plotting rotatory dispersions Darmois proved that the mixtures contain only the two components. Dupont and Desalbres (*15*) have found by experimenting with highly purified α-pinenes that inactive pinene tends to concentrate in the top fractions. Chavannes (*7*), however, by careful fractionation of 30 kilograms of French turpentine has isolated low-boiling unsaturated hydrocarbons.

Dupont applies the same principle for the determination of the composition of the tailings, etc., in terms of β-pinene and nonpinenes, by obtaining the necessary optical data on the dominant "tailings" constituent through fractionation of the end portion in a small column.

With the aid of a special bubbling column (*9*, *10*) (2 meters long with 35-wire gauze plates), Dupont and his associates, applying the Darmois method, have made a comprehensive study of French turpentine and of others of different origin (*2*, *12*).

To provide the data essential for the Darmois method and procure a distillation picture of diagnostic value, an effective means for fractional distillation of the turpentine is of prime importance. Furthermore, the relatively high boiling points of the components, their proximity, and their susceptibility to isomerization and decomposition render it necessary to carry out the fractionation at reduced pressure.

EQUIPMENT

The assembly is shown in Figure 1. The following fractionating columns were tried in this work:

A gauze-plate bubbling column described by Dupont (*12*), of 30 plates, approximately 190 cm. long, and 2.5 cm. in outside diameter.

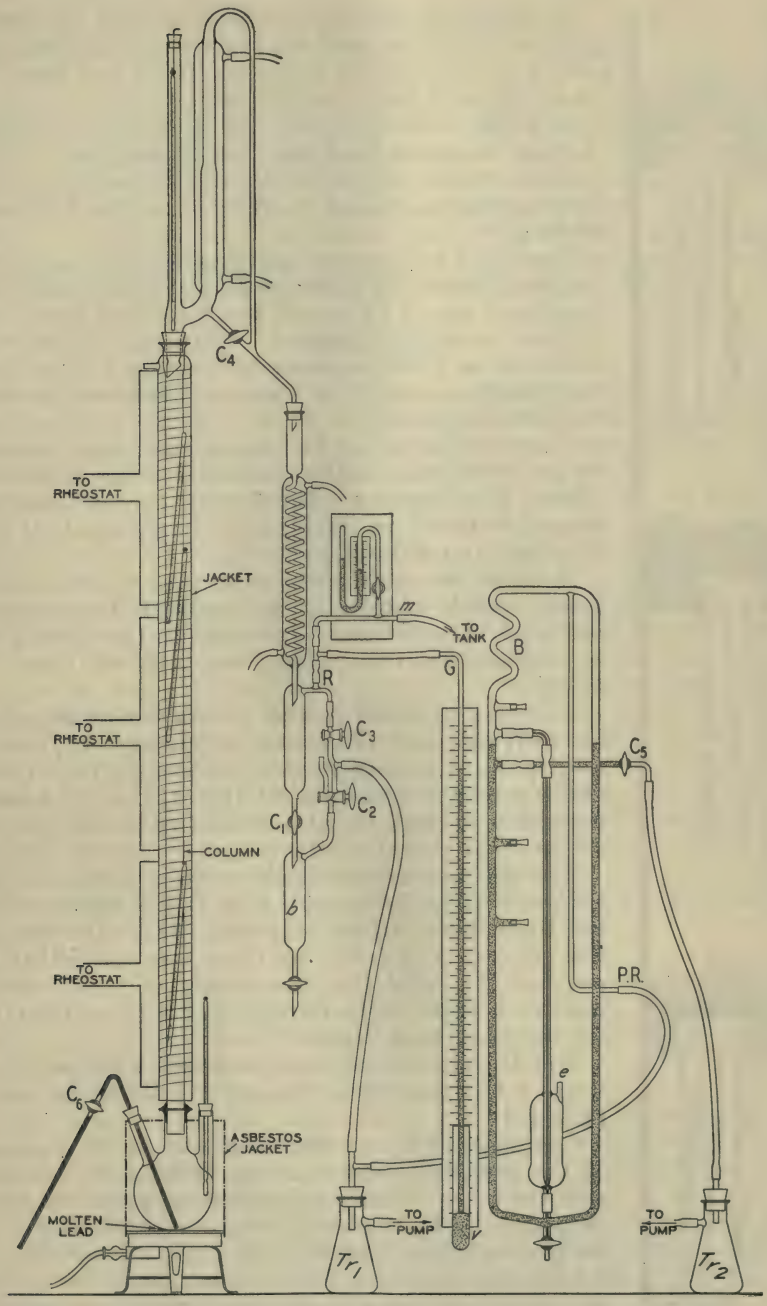


FIG. 1

FIGURE 1.—Assembly for fractionation of turpentine in vacuum, showing column, electrically heated jacket, pressure regulator, dephlegmator-condenser, and other accessory apparatus

FIGURE 2.—Improved gauze plate rectifying column, showing special trap tubes

A bubbling cap-plate column devised by Bruun (*5*), of 15 plates, and approximately 125 cm. long and 2 cm. in outside diameter. This was found to be an effective fractionating device.

A packed column filled with short pieces of glass tubing described by Peters and Baker (*20*). This column, used only in some of the earlier experiments, was not found so effective as the bubbling-plate type.

Improved gauze-plate bubbling columns developed in this division (*19*), one of 15 plates, about 110 cm. long, and one of 32 plates, about 210 cm. long, both 2.5 cm. in outside diameter. (Fig. 2.) These were found to be more resistant to flooding and to function more smoothly in vacuum fractionation than the other columns.

Thermal insulation for the column was provided by an electrically heated jacket, rheostat controlled (*20*). The superior efficiency of lagged over unlagged columns has been shown by Leslie (*16*) and Marshall and Sutherland (*18*).

A large reservoir, serving to take up any slight leaks, aided materially in maintaining continuous and smooth operation during the taking of a fraction when the pump was cut off from the column.

Constant pressure in the system was maintained by a Wade and Merriman regulator[3] (*24*) with modifications to prevent loss of mercury (fig. 1, B), and a trapping arrangement (fig. 1, C_5—Tr_2) made it possible to clean the apparatus (by treatment with dilute acid) without disturbing it.

The dephlegmator-condenser (fig. 1) used with the gauze-plate column is, with slight modification, the form described by Marshall (*17*). Division of the product and reflux in these was controlled by stopcock C_4, and the dimensions of the columns were such as to insure ample reflux without interference by ascending vapors.

The Bruun column was provided with an automatic reflux regulator, the reflux ratio being about 12:1 (*6*).

Operation of the system, as shown in the diagram of the assembly (fig. 1) is as follows: Connection with the pump is made through an appropriate trapping vessel (Tr_1), which in turn is connected with the pressure regulator at P. R. It is connected with a large reservoir (an old steel oxygen cylinder has been found very serviceable), also with a manometer to indicate pressure in the system (with pump on or off), and to a mercury gauge, G, which also serves as a safety valve at V.

[3] This has recently been replaced by a mercury regulator and relay.

During distillation all parts of the apparatus are kept in communication with the pump and the pressure-regulating system and reservoir, through the stopcocks. When taking a fraction, compartment *b* is closed to the rest of the apparatus by stopcock C_1 and is brought to atmospheric pressure through a 2-way stopcock, C_2, the pump remaining in communication with the rest of the system. When the fraction has been taken, communication of column to pump is closed by stopcock C_3, and compartment *b* is evacuated by opening cock C_2 to the pump (the proper pressure point is automatically determined by the pressure regulator), and the whole system is again brought into intercommunication by opening cocks C_3 and C_1.

PROCEDURE

Fractionations were made with the apparatus shown in Figure 1 at constant pressures, some at 20 mm., others at 65 mm. Operations at constant pressure added greatly to the convenience and smoothness of the distillations and facilitated making sharp cuts. Approach to the pure components was indicated readily by the distillation temperatures.

The fractionation of each sample was divided into two steps. All but the last 50 to 100 gm. of sample was distilled in the large apparatus (fig. 1); the remainder, comprising the tailings and some β-pinene, was transferred to a small unit to complete the fractionation. In this the column proper was similar to the Vigreux column (*23*), with thermal insulation, pressure regulator, and other accessory apparatus the same as that described for the large column.

Rotation measurements were made in the green (V=546 mμ) and yellow (J=578 mμ), and occasionally also in the yellow (D=589 mμ), with a Schmidt and Hänsch instrument equipped with a monochromator. The small quantities of various components in the high-boiling fractions are given as tailings. No attempt was made in this investigation to determine its several constituents.

The quantitative data were determined by the Darmois-Dupont optical method on the basis of the Biot relationship (*12, p. 98; 9, 10*):

$$X_1=\frac{(\alpha)_0-(\alpha)_2}{(\alpha)_1-(\alpha)_2}$$

for any given fraction containing the two terpenes in which—

$(X)_1$=the proportion of α-pinene,

$(\alpha)_0$=observed rotation in that fraction.

$(\alpha)_1$=rotation of the pure α-pinene (determined through isolation of this constituent by careful refractionation of the top fractions and occasionally further checked by the plotting method of Darmois).

$(\alpha)_2$=rotation of the β-pinene, which, when obtained from turpentine, regardless of origin (*12*), is found to have a constant value, $\alpha_j=-19.62°$ (10-cm. tube); specific rotation, $(\alpha)_j=-22.44°$.

Beyond the point of pure β-pinene in the series of fractions, the proportions of β-pinene and the nonpinene constituent or tailings were determined from the relationship

$$X_2=\frac{(\alpha)_0-(\alpha)_3}{(\alpha)_2-(\alpha)_3}$$

where $(\alpha)_3$=rotation of the dominant tailings constituent, X_2=proportion of β-pinene having the rotation $(\alpha)_2$, the observed rotation of the fraction being $(\alpha)_0$.

Strictly speaking, specific rotations should be used. As density differences involved are negligible, however, in practice actual rotations are used (*9*).

As pointed out by Dupont, slight errors in the latter calculations (*12, p. 121*) are introduced, as the rotation of the dominant tailings constituent is not obtained with great accuracy, probably owing to the presence of more than two components in the last few fractions. These fractions, however, are too small to affect the general accuracy of the determinations.

RESULTS

Analytical data on the various turpentine samples examined are given in Table 1. Samples 2, 8, 9, 10, and 11 were obtained from authentic oleoresins[4] by steam distillation in the usual manner.

TABLE 1.—*Analytical data on turpentine samples from commercial and authentic sources*

Source and sample No.	Rotation (10-cm. tube)		Refractive index $(n_D^{25°})$	Density $(d^{15.6°})$	Composition		
	α_j=578mμ.	α_v=546mμ.			α-pinene	β-pinene	Tailings
Commercial from mixed fields of slash and longleaf pine:					*Per cent*	*Per cent*	*Per cent*
G–7	−2.4	−2.2	1.4697	0.8707	63.0	31.5	5.6
G–15	−9.2	−9.98	1.4692	.8662	61.9	32.6	5.3
G–16	+1.9	+2.5	1.4680	.8664	62.2	28.8	6.1
B–1	−1.58	−12.58	1.4701	.8692	59.2	36.9	3.9
Samples from authentic sources:							
Slash pine 3, old	−20.50	−22.56	1.4698 1.4663	.8667 .8624	58.0	35.6	6.4
Longleaf 1, fresh	+14.04	+16.27	1.4691	.8680	68.4	28.6	3.01
Longleaf pine 2, fresh	+12.29	+14.34	1.4692	.8694	62.5	33.3	4.2
Gum dip 8, slash	−22.58	−24.9	1.4694	.8657	61.0	33.7	5.3
Gum dip 9, longleaf	+11.0	+12.86	1.4690	.8667	62.5	34.4	3.1
Scrape 10, slash	−25.05	−27.8	1.4700	.8704	58.8	33.6	7.6
Scrape 11, longleaf	+7.35	+8.85	1.4681	.8675	67.0	29.2	3.8

Longleaf pine No. 1 represents a commercial turpentine obtained from an area in Mississippi known to be exclusively longleaf.

Slash pine No. 3 represents a sample from an authentic source which had been in storage for about four years.

Samples G–7, G–15, and G–16 were obtained from commercial turpentines which had been kept in storage in tanks for several years (approximately closed from the atmosphere).

Sample B–1 represents a commercial turpentine obtained from mixed longleaf and slash gum.

Typical detailed fractionations of a sample each of slash and longleaf pine are given in Tables 2 and 3. Data on rotations, rotatory dispersions, refractive indices, and densities of the fractions, plotted against weight, are shown in Figures 3, 4, 5, and 6. Normal inflections are noticeable with the change from the relatively pure α-pinene

[4] Prepared by W. C. Smith, of this division, from oleoresins made available by the Forest Products Laboratory in connection with another investigation.

to the mixtures with β-pinene, and from these to the β-pinene. Influence of the tailings on the properties of the β-pinene is shown by the sharp inflections just beyond the β-pinene points of the respective curves.

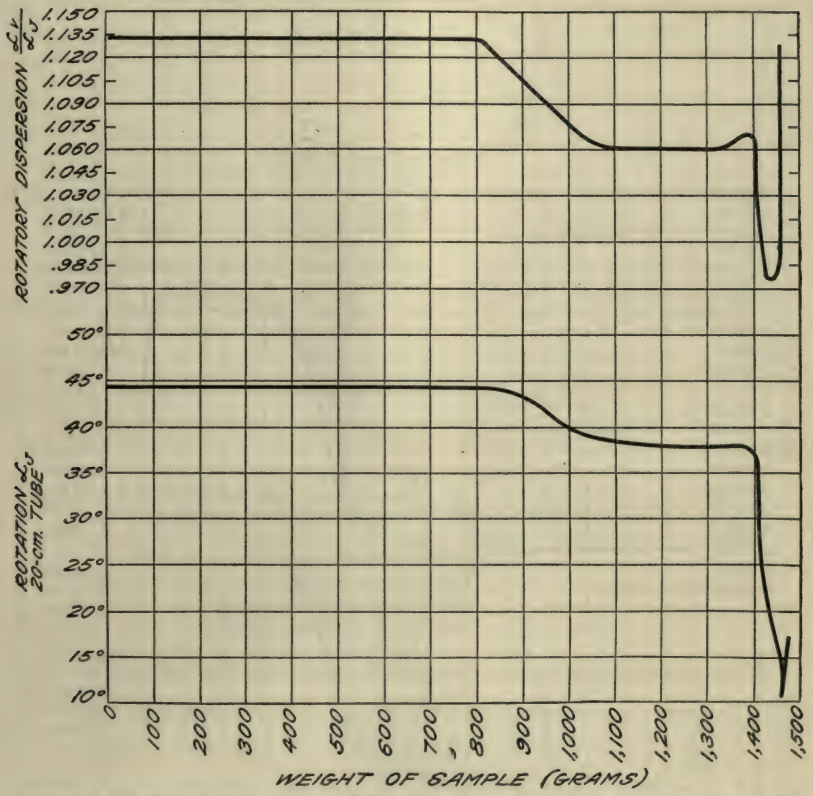


FIGURE 3.—Rotations and rotatory dispersions of fractions from slash-pine turpentine

A break in the continuity of rotatory dispersions of longleaf pine turpentine occurs at the point (fraction 10) of change from dextro α-pinene to levo β-pinene and is not indicative of a new component as shown by the continuity of the rotations, refractive indices, and densities in the corresponding regions.

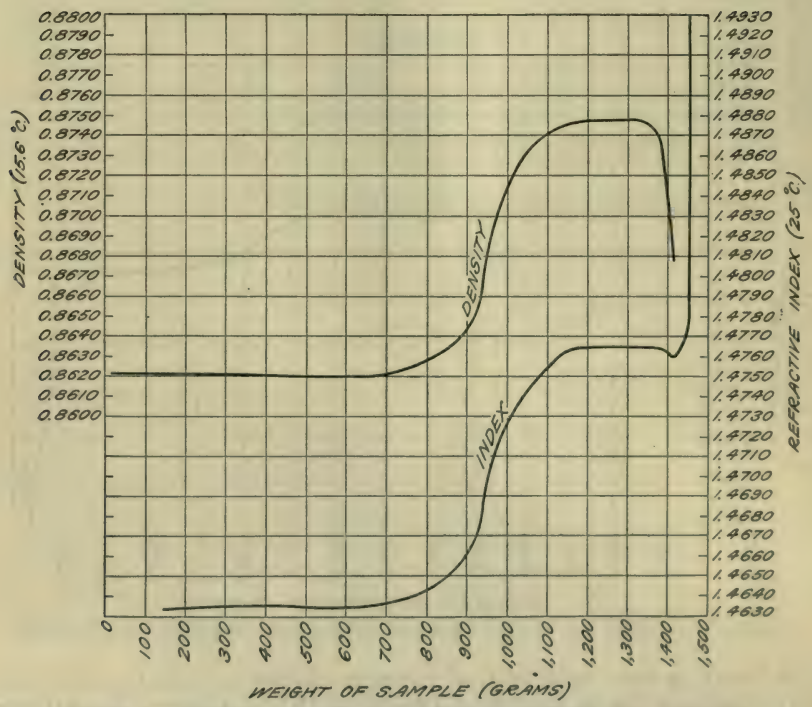


FIGURE 4.—Densities and refractive indices of fractions from slash-pine turpentine

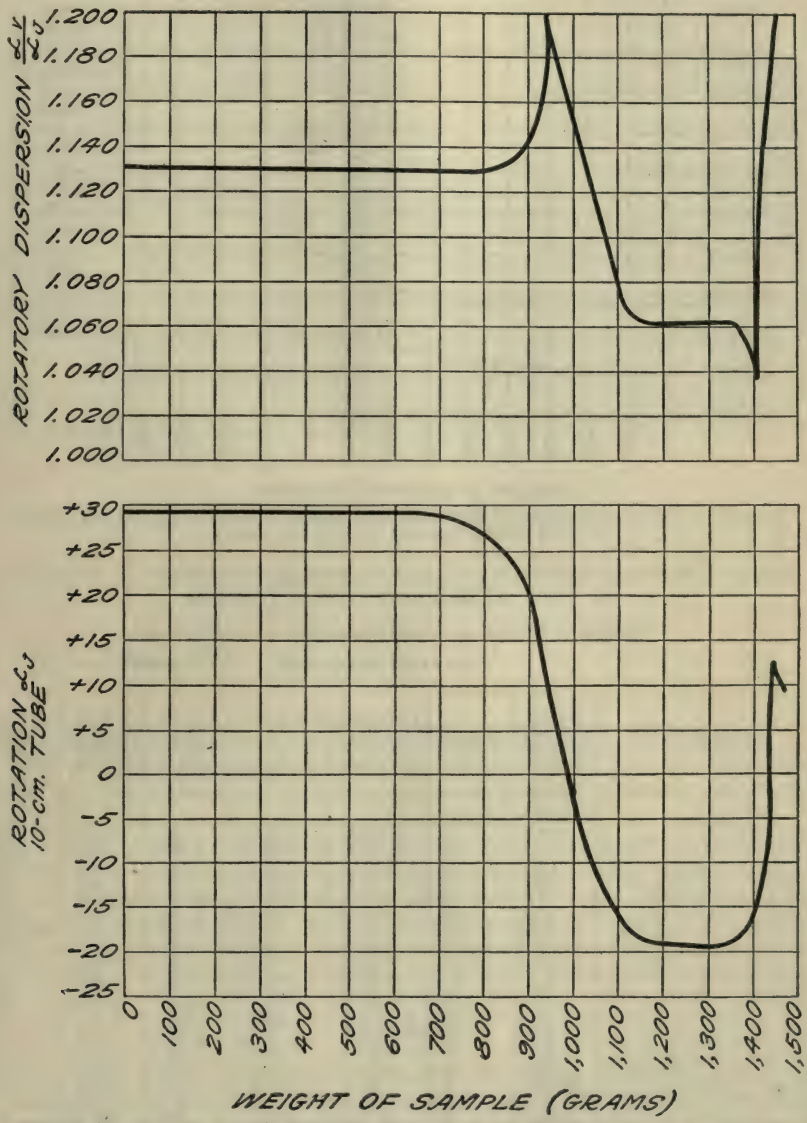


FIGURE 5.—Rotations and rotatory dispersions of fractions from longleaf-pine turpentine

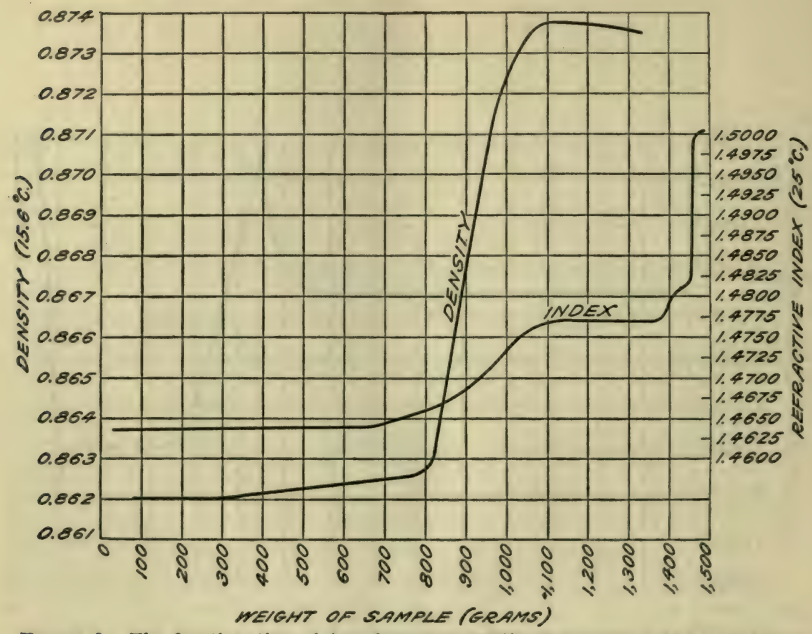


FIGURE 6.—The fractionation of American gum spirits of turpentine and evaluation of its pinene content by optical means

TABLE 2.—*Fractional distillation of 1,500 grams of turpentine (3, slash pine, old, Table 1) and properties of fractions*

[Original turpentine: $\alpha_j = -40.1$ (20-cm. tube) $n_D^{25°} = 1.4698$
$\alpha_v = -45.12$ (20-cm. tube) $d^{15.6°} = 0.8667$]

Fraction No.	Boiling temperature at 20 mm.	Weight	Rotation (20-cm. tube)		Dispersion $\left(\frac{\alpha_v}{\alpha_j}\right)$	Refractive index $\left(n_D^{25°}\right)$	Density $\left(d^{15.6°}\right)$
			$\alpha_j = 578 m\mu$	$\alpha_v = 546 m\mu$			
	° C.	Grams					
1	51.0	33	−44.45	−50.17	1.129	1.4633	
2	51.0	45	−44.4	−50.15	1.130	1.4634	0.8620
3	51.0	53	−44.6	−50.4	1.130	1.4635	.8620
4	51.0	87	−44.7	−50.45	1.129	1.4635	.8620
5	51+	119	−45.0	−50.9	1.129	1.4635	.8620
6	51.4	97	−45.10	−50.9	1.129	1.4634	.8624
7	51.2	137	−45.2	−51.05	1.130	1.4634	
8	51.5	90	−45.15	−50.95	1.128	1.4637	.8628
9	51.8	150	−45.15	−50.95	1.128	1.4847	
10	56.8	100	−43.15	−47.55	1.102	1.4693	.8679
11	58.1	80	−40.55	−43.70	1.078	1.4736	.8722
12	58.2	85	−38.70	−41.1	1.062	1.4765	.8737
13	58.2	88	−38.05	−40.35	1.063	1.4766	.8733
14	58.2	86	−37.75	−40.00	1.060	1.4766	.8737
15	58.4	78	−37.5	−39.8	1.061	1.4765	.8730
16	68.0	61	−38.3	−41.1	1.073	1.4772	.8582
17[2]	68–69.0	20	−29.8	−31.3	1.050	1.4814	
18	67.8	20	−19.9	−19.9	1.00	1.4816	
19	69.2	19	−16.5	−15.8	.976	1.4817	
20	93.8	12	−10.70	−10.5	.981	1.4830	
21	[3]91.0	11	−17.10	−19.3	1.129	1.5005	
22	[3]120	6	−50.0	−50.0			
Residue		11					
1 to 9 (combined)		811	−44.4	−50.25	1.132	1.4635	.8622
12 to 15 (combined)		337	−38.1	−40.5	1.0604	1.4766	.8735

[1] Composition as calculated from data in table: α-pinene, 58.0 per cent; β-pinene, 35.6 per cent; tailings 6.4 per cent. Rotation of α-pinene: $\alpha_j = -45.2°$ (20-cm. tube).
[2] 79 grams, representing remainder of the sample, was transferred to small apparatus and fractionated, giving fractions 18 to 22.
[3] At 12 mm.

TABLE 3.—*Fractional distillation of 1,500 grams of turpentine*[1] *(longleaf 2, Table 1) and properties of fractions*

Original turpentine: α_j=+12.29 (10-cm. tube) $n_D^{25°}$=1.4692
α_v=+14.34 (10-cm. tube) $d^{15.6°}$=0.8694]

Fraction No.	Boiling temperature at 20 mm.	Weight	Rotation (10-cm. tube)		Dispersion $\left(\frac{\alpha_v}{\alpha_j}\right)$	Refractive index $\left(n_D^{25°}\right)$	Density $\left(d^{15.6°}\right)$
			α_j=578 mμ	α_v=546 mμ			
	° C.	Grams					
1	51.0	112	+29.12	+32.78	1.128	1.4634	
2	51.2	103	+29.54	+33.20	1.126	1.4634	
3	51.4	90	+29.44	+33.15	1.126	1.4634	0.8622
4	51.6	102	+29.39	+33.18	1.129	1.4634	
5	51.6	102	+29.40	+33.17	1.128	1.4634	
6	51.6	105	+29.98	+32.72	1.129	1.4635	
7	51.8	102	+28.51	+32.17	1.128	1.4636	.8620
8	52.2	85	+26.71	+30.24	1.130	1.4642	.8629
9	53.8	90	+21.97	+24.94	1.135	1.4656	.8637
10	56.8	52	+8.54	+10.24	1.199	1.4691	.8674
11	57.2	98	−10.10	−10.30	1.019	1.4740	.8728
12	58.4	98	−18.66	−19.81	1.062	1.4761	
13	58.4	99	−19.34	−20.50	1.060	1.4763	.8747
14	58.6	76	−19.31	−20.46	1.060	1.4763	
15	58.6	51	−19.03	−20.24	1.063	1.4761	
16[2]	59.5	45	−14.71	−15.26	1.037	1.4758	
17	76.0	24	−9.41	−9.58	1.018	1.4754	
18	101.0	10	+12.49	+14.39	1.152	1.4824	
19	[3]60–71	8	+12.38	+14.58	1.177	1.4955	
20	[3]80	9	+8.10	+9.88	1.219	1.4895	
[illegible]		21					
[illegible]		614	+29.22	+33.065	1.131	1.4635	.8622
[illegible]		324	−19.08	−20.225	1.060	1.4766	.8747

[illegible] 62.5 per cent; β-pinene, 33.3 per cent; tailings,

[illegible]paratus.

[illegible]g re-
[illegible]t with
vapor

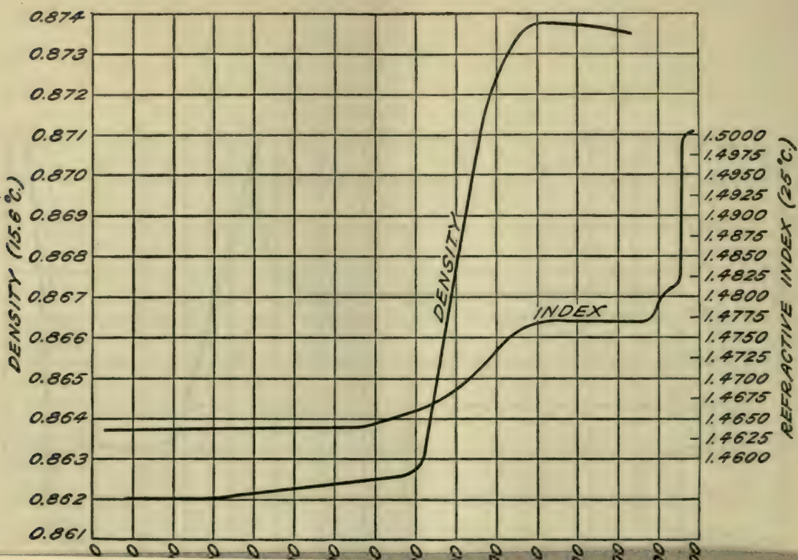
pinene
fractions w[illegible] terature
was generally obtained [illegible] ctive in-
dices for the α-pinene components, [illegible] ith those
reported by several authors, were all somewhat [illegible] those re-
ported by Dupont and Desalbres (*15*) for the pure compounds, but several refractionations showed no appreciable change. Rotatory dispersion is of particular diagnostic significance. The values given for the two terpenes are: α-pinene=1.133; β-pinene=1.0615 (*15*).

SUMMARY

An assembly is described, comprising plate rectifying column, pressure regulator, and other accessory apparatus, which has been found to function very smoothly and satisfactorily for the fractionation of turpentine in vacuum.

By distilling at fixed pressures, distillation temperatures become reasonably accurate reference points in the approach to the pure components, and closer correlation of distillation temperatures with composition of the respective fractions becomes possible.

Data relating to the composition of a number of turpentines with respect to the α and β pinene and tailings are given, their proportions



Correction

Technical Bulletin No. 276, U. S. Department of Agriculture

Page 10, Figure 6: The legend should read, "Densities and refractive indices of fractions from long-leaf pine turpentine

Fraction No.	temperature at 20 mm.	Weight	$\alpha_j = 578 m\mu$	$\alpha_v = 546 m\mu$	sion $\left(\frac{\alpha_v}{\alpha_j}\right)$	tive index $\left(n^{25°}_D\right)$	$\left(d^{15.6°}\right)$
	° C.	*Grams*					
1	51.0	33	−44.45	−50.17	1.129	1.4633	----------
2	51.0	45	−44.4	−50.15	1.130	1.4634	0.8620
3	51.0	53	−44.6	−50.4	1.130	1.4635	.8620
4	51.0	87	−44.7	−50.45	1.129	1.4635	.8620
5	51+	119	−45.0	−50.9	1.129	1.4635	.8620
6	51.4	97	−45.10	−50.9	1.129	1.4634	.8624
7	51.2	137	−45.2	−51.05	1.130	1.4634	----------
8	51.5	90	−45.15	−50.95	1.128	1.4637	.8628
9	51.8	150	−45.15	−50.95	1.128	1.4847	----------
10	56.8	100	−43.15	−47.55	1.102	1.4693	.8679
11	58.1	80	−40.55	−43.70	1.078	1.4736	.8722
12	58.2	85	−38.70	−41.1	1.062	1.4765	.8737
13	58.2	88	−38.05	−40.35	1.063	1.4766	.8733
14	58.2	86	−37.75	−40.00	1.060	1.4766	.8737
15	58.4	78	−37.5	−39.8	1.061	1.4765	.8730
16	68.0	61	−38.3	−41.1	1.073	1.4772	.8582
17[2]	68–69.0	20	−29.8	−31.3	1.050	1.4814	----------
18	67.8	20	−19.9	−19.9	1.00	1.4816	----------
19	69.2	19	−16.5	−15.8	.976	1.4817	----------
20	93.8	12	−10.70	−10.5	.981	1.4830	----------
21	[3] 91.0	11	−17.10	−19.3	1.129	1.5005	----------
22	[3] 120	6	−50.0	−50.0	----------	----------	----------
Residue	----------	11	----------	----------	----------	----------	----------
1 to 9 (combined)	----------	811	−44.4	−50.25	1.132	1.4635	.8622
12 to 15 (combined)	----------	337	−38.1	−40.5	1.0604	1.4766	.8735

[1] Composition as calculated from data in table: α-pinene, 58.0 per cent; β-pinene, 35.6 per cent; tailings 6.4 per cent. Rotation of α-pinene: $\alpha_j = -45.2°$ (20-cm. tube).

[2] 79 grams, representing remainder of the sample, was transferred to small apparatus and fractionated, giving fractions 18 to 22.

[3] At 12 mm.

TABLE 3.—*Fractional distillation of 1,500 grams of turpentine*[1] *(longleaf 2, Table 1) and properties of fractions*

Original turpentine: $\alpha_j = +12.29$ (10-cm. tube) $n_D^{25°} = 1.4692$
$\alpha_v = +14.34$ (10-cm. tube) $d^{15.6°} = 0.8694$]

Fraction No.	Boiling temperature at 20 mm.	Weight	Rotation (10-cm. tube)		Dispersion $\left(\frac{\alpha_v}{\alpha_j}\right)$	Refractive index $\left(n_D^{25°}\right)$	Density $\left(d^{15.6°}\right)$
			α_j=578 mμ	α_v=546 mμ			
	° C.	Grams					
1	51.0	112	+29.12	+32.78	1.128	1.4634	
2	51.2	103	+29.54	+33.20	1.126	1.4634	
3	51.4	90	+29.44	+33.15	1.126	1.4634	0.8622
4	51.6	102	+29.39	+33.18	1.129	1.4634	
5	51.6	102	+29.40	+33.17	1.128	1.4634	
6	51.6	105	+29.98	+32.72	1.129	1.4635	
7	51.8	102	+28.51	+32.17	1.128	1.4636	.8620
8	52.2	85	+26.71	+30.24	1.130	1.4642	.8629
9	53.8	90	+21.97	+24.94	1.135	1.4656	.8637
10	56.8	52	+8.54	+10.24	1.199	1.4691	.8674
11	57.2	98	−10.10	−10.30	1.019	1.4740	.8728
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Residue		21					
1 to 6 (combined)		614	+29.22	+33.065	1.131	1.4635	.8622
12 to 15 (combined)		324	−19.08	−20.225	1.060	1.4766	.8747

[1] Composition as calculated from data in table: α-pinene, 62.5 per cent; β-pinene, 33.3 per cent; tailings, 4.2 per cent. Rotation of α-pinene: $\alpha_j = +30.5°$ (10-cm. tube).
[2] 72 grams, representing remainder of sample, was transferred to small apparatus.
[3] At 3 mm.

The distillation temperatures for the fractions representing respectively the α and β pinene components are in fair agreement with the temperatures for these compounds corresponding to a vapor pressure of 20 mm. as reported by Pickett and Peterson (*21*).

Reasonable agreement in the other properties of the α and β pinene fractions with those of the pure compounds reported in the literature was generally obtained by the one fractionation. The refractive indices for the α-pinene components, although in agreement with those reported by several authors, were all somewhat higher than those reported by Dupont and Desalbres (*15*) for the pure compounds, but several refractionations showed no appreciable change. Rotatory dispersion is of particular diagnostic significance. The values given for the two terpenes are: α-pinene=1.133; β-pinene=1.0615 (*15*).

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Data relating to the composition of a number of turpentines with respect to the α and β pinene and tailings are given, their proportions

having been ascertained optically by the method of Darmois and Dupont.

No great variation was noted in the total of the two components, α and β pinene. Although material differences were noted in their proportions, such differences do not seem to be ascribable to the variety of pine (longleaf or slash) or to the dip or scrape form of either.

As regards the tailings, however, as well as may be judged from the limited number of samples examined, a generally higher content is indicated in the slash-pine turpentine than in the longleaf, and as may be expected, the old turpentine contains more than the fresh turpentine. In view of the influence of the tailings components on yields in industrial syntheses, this observation, if found to be true generally, would have a greater significance than would at first be apparent.

There is apparently no indication, however, that the increase of slash pine as a source of American turpentine will tend to diminish its β-pinene content.

The increase of turpentine of negative rotation with the increasing use of slash pine is doubtless due to the negatively rotating character of the α-pinene in the latter and not to any material change in the proportion of α and β pinene.

LITERATURE CITED

(1) AUSTERWEIL, G.
1927. PROCÉDÉ POUR LA PRÉPARATION DE BORNÉOL ET D'ISOBORNÉOLS. French Patent No. 621,954. Issued February 14, 1927.

(2) BARRAUD, M.
1928. L'ÉTAT DE NOS CONNAISSANCES SUR LA COMPOSITION DES ESSENCES DE TÉRÉBENTHINE. Bul. Inst. du Pin 58: 93–97.

(3) BORNEMAN, F.
1930. NATURCAMPHER UND SYNTHETISCHER CAMPHER II. Chem. Ztg. 54: 22–23.

(4) BRUS, G.
1930. OZONIDES DU PINÈNE ET DU NOPINÈNE. Bul. Inst. du Pin (2) 2: 35–38, illus.

(5) BRUUN, J. H.
1929. LABORATORY RECTIFYING COLUMNS WITH NON-SIPHONING BUBBLING-CAP PLATES. Indus. and Engin. Chem., Analyt. Ed. 1: 212–213, illus.

(6) ———
1930. CONVENIENT REFLUX REGULATOR FOR LABORATORY STILLS. Indus. and Engin. Chem., Analyt. Ed. 2: 187–188, illus.

(7) CHAVANNES, G.
1930. SUR UN HYDROCARBURE DE L'ESSENCE DE RESINE ET LES 1.2 DIMÉTHYL-CYCLOPENTANES STÉRÉOISOMÈRES. Bul. Soc. Chim. Belg. 39: 402–411.

(8) DESALBRES, L.
1929. INDUSTRIE DE LA TERPINE ET DU TERPINÉOL. Bul. Inst. du Pin 56: 10–14, illus.

(9) DUPONT, G.
1922. COMPOSITION ET APPLICATIONS INDUSTRIELLES DES ESSENCES DE TÉRÉBENTHINE. LES CONSTITUANTS DE L'ESSENCE DE PIN MARITIME. Chim. et Indus. [Paris] 8: 549–552, illus.

(10) ———
1922. LES CONSTITUANTS DE L'ESSENCE DE PIN MARITIME. Chim. et Indus. [Paris] 8: 553–554, illus.

(11) ———
1922. ACTION DES DIVERS CONSTITUANTS DANS LES SYNTHÈSES INDUSTRIELLES. Chim. et Indus. [Paris] 8: 555–558.

(12) DUPONT, G.
1926. LES ESSENCES DE TÉRÉBENTHINE. 332 p., illus. Paris.
(13) ———
1929. SUR L'OXYDATION PERMANGANIQUE DU NOPINÈNE. Bul. Inst. du Pin 65: 269–270.
(14) ——— and BARRAUD, M.
1929. SUR LA COMPOSITION DE L'ESSENCE DE TÉRÉBENTHINE AMÉRICAINE. Bul. Inst. du Pin 60: 155–156.
(15) ——— and DESALBRES, L.
1923. SUR LA NATURE DES PRODUITS DE TÊTE DE QUELQUES ESSENCES DE TÉRÉBENTHINE ET SUR LES CONSTANTES DES CONSTITUANTS PURS DE CES ESSENCES. Bul. Soc. Chim. France (4) 33: 1252–1262, illus.
(16) LESLIE, E. H.
1923. MOTOR FUELS; THEIR PRODUCTION AND TECHNOLOGY. 681 p., illus. New York.
(17) MARSHALL, M. J.
1928. IMPROVED LABORATORY RECTIFYING COLUMN. Indus. and Engin. Chem. 20: 1379, illus.
(18) ——— and SUTHERLAND, B. P.
1927. EFFECTIVENESS OF LABORATORY RECTIFYING COLUMN. Indus. and Engin. Chem. 19: 735–738, illus.
(19) PALKIN, S.
1931. AN IMPROVED GAUZE PLATE LABORATORY RECTIFYING COLUMN. Indus. and Engin. Chem., Analyt. Ed. 3: 377–378, illus.
(20) PETERS, W. A., and BAKER, T.
1926. HIGH-PRECISION FRACTIONAL DISTILLATION IN THE LABORATORY. Indus. and Engin. Chem. 18: 69–72, illus.
(21) PICKETT, O. A., and PETERSON, J. M.
1929. TERPENES AND TERPENE ALCOHOLS. I—VAPOR PRESSURE—TEMPERATURE RELATIONSHIPS. Indus. and Engin. Chem. 21: 325–326, illus.
(22) VEITCH, F. P., and GROTLISCH, V. E.
1921. TURPENTINE; ITS SOURCES, PROPERTIES, USES, TRANSPORTATION, AND MARKETING WITH RECOMMENDED SPECIFICATIONS. U. S. Dept. Agr. Bul. 898, 53 p., illus. (Revised.)
(23) VIGREUX, H.
1904. NOUVEAU RÉFRIGÉRANT ET NOUVELLE COLONNE À DISTILLER DANS LE VIDE OU À LA PRESSION NORMALE. Bul. Soc. Chim. France (3) 31: 1116–1119, illus.
(24) WADE, J., and MERRIMAN, R. W.
1911. APPARATUS FOR THE MAINTENANCE OF CONSTANT PRESSURES ABOVE AND BELOW THE ATMOSPHERIC PRESSURE. APPLICATION TO FRACTIONAL DISTILLATION. Jour. Chem. Soc. [London] Trans. 99: 984–997, illus.

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